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JOHN L. RICH
EDITOR

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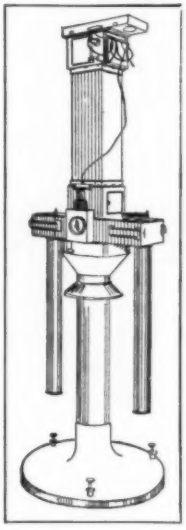

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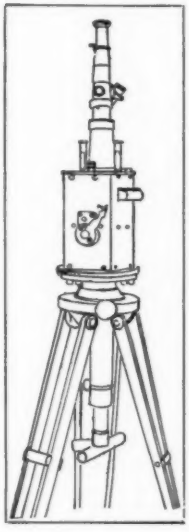

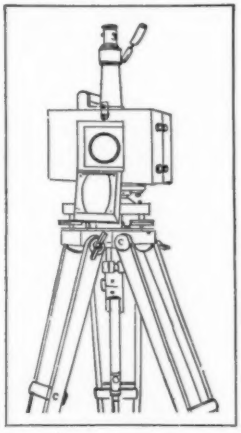

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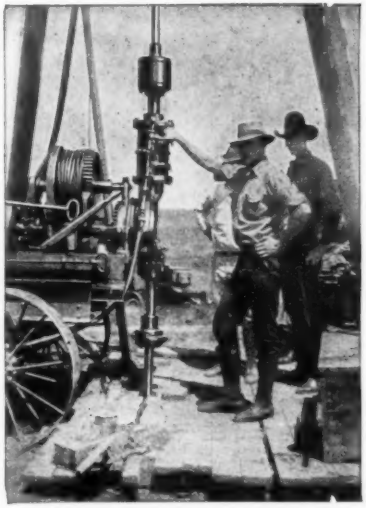
—"drilled again, core again, gone again, *Sullivan.*"



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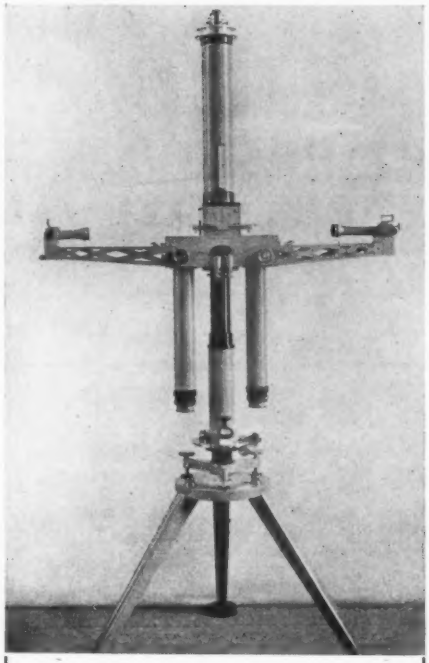

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SEPTEMBER 1926

THE PERMIAN OF ARIZONA AND NEW MEXICO[1]

N. H. DARTON
U.S. Geological Survey, Washington, D.C.

ABSTRACT

The Permian is represented in the southwestern United States by limestones and sandstones, the latter in part red, and local deposits of gypsum and salt. In Arizona the principal formations are the Kaibab limestone, Coconino sandstone, and the greater part of the Supai formation. Part of the Naco limestone in the southern part of the state is Permian and strata of that age have been found in the southwestern part of the state. In the Holbrook dome and Defiance uplift the Kaibab limestone thins out and the Coconino sandstone is extensively exposed while in part of this area the red beds of the Supai formation lie on pre-Cambrian granite and quartzite.

In New Mexico these strata are represented by the Chupadera formation consisting mainly of limestone, gray and red sandstone, and gypsum, and the red Abo sandstone. The latter lies on limestone of the Magdalena group (Pennsylvanian) but overlaps locally on pre-Cambrian rocks notably in Zuni, Nacimiento, and Pedemal mountains. Under much of eastern New Mexico the Chupadera formation includes thick deposits of salt and anhydrite. To the south the formation merges laterally into the limestones and sandstones of the Guadalupe group which carries a large and remarkably different fauna. This change of life indicates a great change in environmental conditions in a short distance which is difficult to explain. Over the Guadalupe and Chupadera strata lie the thick Castile gypsum and the Rustler limestone, which are probably also of Permian age.

CLASSIFICATION

For a long time the formations in New Mexico and Arizona now classed as Permian were regarded as Pennsylvanian in age. In 1904 and 1905 Lee[2] examined these strata in central New Mexico and separated them from the underlying Magdalena group under the name Manzano group, the fauna of which was regarded as upper

[1] Published by permission of the Director, U.S. Geological Survey.

[2] Willis T. Lee and George H. Girty, "The Manzano Group of the Rio Grande Valley, New Mexico," *U.S. Geol. Survey Bulletin No. 389*, 1909. Pp. 1-141; Plates 1-12.

Pennsylvanian. The similar fauna in the Aubrey group in the Grand Canyon region was also classed[1] as upper Pennsylvanian. This fauna, however, was regarded as older than the Guadalupian fauna of Guadalupe Mountain in northern Texas, which was considered true Permian.[2] In the course of field work extending over most parts of New Mexico and Arizona during the last twenty-three years my associates and I have obtained paleontologic and stratigraphic evidence that the Manzano and Aubrey groups are of Permian age. The formations are described in detail in reports[3] prepared some years ago and now in course of publication, and only the more significant features will be presented in this paper.

The first published announcements regarding the Permian age of the Manzano group were a footnote in the guidebook of the Santa Fe Railroad in 1915;[4] notes by Lee[5] in 1917 and 1920 emphasizing the significance of the physical break at its base; a general statement regarding its age in a report on the Permian salt deposits in 1921[6] and in my description of geologic structure of New Mexico in 1922.[7] The formations of the Aubrey group are classed as Permian on the geological map of Arizona recently published by the Arizona Bureau of Mines and in the résumé of Arizona geology referred to above. The

[1] N. H. Darton, "A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona," *U.S. Geol. Survey Bulletin No. 435*, 1910. Pp. 1-88. Plates; map.

[2] G. H. Girty, "The Guadalupian Fauna," *U. S. Geol. Survey Prof. Paper No. 58*, 1908.

[3] N. H. Darton, "Résumé of Arizona Geology," *Arizona Bureau of Mines Bulletin 119*, Tucson, 1926; N. H. Darton, "Red Beds and Associated Formations in New Mexico, with an Outline of the Geology of the State," *U. S. Geol. Survey Prof. Paper* (will probably be printed in 1927); N. H. Darton, "Geologic Map of New Mexico, Scale, 1/500,000," *U. S. Geol. Survey* (in press).

[4] N. H. Darton, "Guidebook of the Western United States, Part C, The Santa Fe Route, with a Side Trip to the Grand Canyon of the Colorado," *U. S. Geol. Survey Bulletin No. 613* (1915), p. 75.

[5] W. T. Lee, "General Stratigraphic Break between the Pennsylvanian and Permian in Western America," *Geol. Society of America Bulletin*, Vol. 28 (1917), pp. 169-70; and "Notes on the Manzano Group," *American Journal of Science*, Vol. 49 (1920), p. 325.

[6] N. H. Darton, "Permian Salt Deposits of the South-central United States," *U. S. Geol. Survey Bulletin No. 715* (1921), pp. 205-30, map.

[7] N. H. Darton, "Geologic Structure of Parts of New Mexico," *U. S. Geol. Survey Bulletin No. 726* (1922), pp. 173-275, plates 30-48.

evidence as to Permian age of these two groups is mainly paleontologic. Detailed studies of the molluscan faunas by Girty convinced him that they were much younger than the fauna of the underlying Magdalena group and the Pennsylvanian portion of the original Redwall limestone, and fossil plants from many places in the lower red sandstones are regarded as Permian by David White. Further strong evidence was the fact that when traced through the Sacramento Mountains and southward, the upper limestones grade laterally into the strata yielding the Guadalupian fauna. It was found also that the beds yielding bones of Permian animals near Coyote in Rio Arriba County probably are Abo (lower Manzano). Molluscan fossils from limestone members low in these red beds (Abo and Supai) in western New Mexico and Arizona are of the Manzano fauna. This fauna is also present in the upper part of the Naco limestone in southeastern Arizona and in limestones at many places farther west in southern Arizona.

SUBDIVISIONS

In 1910[1] it was thought desirable to rename the subdivisions of the Aubrey group—Kaibab limestone, Coconino sandstone, and Supai formation, with type localities in the Grand Canyon region. In the course of field work covering all of the outcrop of the Manzano group in New Mexico it was impracticable in many places to separate the San Andres limestone and Yeso formation of Lee, so these have been combined in the Chupadera formation. This and the underlying Abo sandstone are the two components of the Manzano group as described in my report on structures in New Mexico and represented on the geological map of New Mexico, now in course of publication.

For the present the extension of the Delaware Mountain formation and Capitan limestone (Guadalupe group) and most of the associated limestones and red beds of the Lower Pecos Valley in New Mexico are included in the Chupadera formation, but the Castile gypsum and Rustler limestone, although of probable Permian age, are not included in that formation. The Gym limestone[2] (Permian)

[1] N. H. Darton, *op. cit.*, *Bulletin 435*, pp. 25–32.

[2] N. H. Darton, "Geology and Underground Water of Luna County, New Mexico," *U. S. Geol. Survey Bulletin No. 618*, 1916, and *Deming Folio No. 207*, 1917.

in Luna County, New Mexico, has been separated because its range of equivalency is not indicated.

The Chupadera formation, excepting possibly some basal red beds, is the eastern extension of the Coconino sandstone and Kaibab limestone, both of which are easily recognized in the Zuni Mountain uplift and in places farther east. The red beds of the Abo formation are equivalent to the red beds of the Supai formation, but the latter probably includes the equivalent of part, or all, of the red basal Chupadera beds. In both states limestone members in the medial and lower portions of the Abo and the original Supai formations carry the same Permian fossils. Noble,[1] however, has recently redefined the Supai formation in the Grand Canyon region and placed in its lower portion a limestone with Pennsylvanian fossils formerly classified as the upper member of the Redwall limestone, and therefore not regarded as part of the Aubrey group. Eventually this limestone may be separated as a formational unit, for which possibly the name Magdalena would be suitable, for in general it is equivalent to all, or part of that group in New Mexico. In central Arizona the strata carrying Pennsylvania fossils are included in the upper part of the Tornado limestone of Ransome, and in southern Arizona they constitute the lower part of the Naco limestone, but doubtless these two formations will be subdivided. The Hermit shale, a body of red sediment which occupies an area of considerable extent in the Grand Canyon region and formerly was regarded as a local upper member of the Supai formation, has been separated as a formation by Noble. It is of Permian age, and, although separated from the underlying red sandstones by marked unconformity, the latter are Permian also, as shown by abundant fossils in east-central Arizona, so that the hiatus is by no chance the same as the long one which separates the Manzano and Magdalena groups in New Mexico.

The principal features of nomenclature and equivalency are given in the following table (Table I), which sets forth the classification now in use by the United States Geological Survey:

[1] L. F. Noble, "A Section of the Paleozoic Formation of the Grand Canyon at the Bass Trail," *U. S. Geol. Survey Prof. Paper No. 131* (1923), pp. 23–73, plates XIX–XXV.

TABLE I

TABLE OF CLASSIFICATION OF PERMIAN AND ASSOCIATED ROCKS IN NORTHERN ARIZONA AND NEW MEXICO*

AGE	NORTHERN ARIZONA	NEW MEXICO		NORTHWEST TEXAS
		West	East	
Triassic	Moenkopi formation (Lower Triassic)	Dockum (Upper Triassic) Moenkopi (Lower Triassic)		Dockum group
	Unconformity	Unconformity		Unconformity
Permian	.... Kaibab limestone Coconino sandstone underlain locally by Hermit shale unconformably on Supai formation including strata of Pennsylvanian age.	..... Rustler limestone ..... Castile gypsum Chupadera formation (Gym limestone to southwest)		Rustler limestone Castile gypsum Capitan limestone Delaware Mountain formation Guadalupe group (?) Hueco limestone
Pennsylvanian		Abo sandstone Magdalena group		Absent (Unconformity)
Mississippian	..... Redwall limestone (early Mississippian)	..... Lake Valley limestone (early Mississippian)		(Late Mississippian) .....

* By N. H. Darton.

SUPAI FORMATION

GENERAL RELATIONS

The plateau region of northern Arizona is underlain by the thick series of red sandstone and shale of the Supai formation, which extends far south of Mogollon Escarpment and Verde Breaks in the many ridges of the White River basin. It appears also in the Virgin Mountains and the downfaulted blocks on Colorado River below the Grand Canyon. Apparently it is not represented in the Upper Carboniferous succession in the southern part of the state, but there is no indication of the original southern limit of Supai deposition, as erosion has removed the strata in a wide area in central Arizona. The Permian age of the overlying Hermit shale is indicated by plants, and limestone members in the red Supai beds south of the Mogollon Escarpment contain an abundant Permian molluscan fauna, which will be described herewith.

GRAND CANYON—ARIZONA PLATEAU

The thick succession of Permian strata in the Arizona Plateau is superbly exposed for more than 200 miles in the upper part of the walls of Grand Canyon. The formations are as follows:

	Average Thickness (Feet)
Kaibab limestone (surface mostly eroded)	300–700
Coconino sandstone, light gray, massive, cross-bedded	150–600
Hermit shale; bright red shale	150–500+
Supai formation; sandstone, mostly red, slabby to massive, with limestones (Pennsylvanian) in lower part	800–1100

The outcrop of the red rocks of the Supai formation is very conspicuous throughout the Grand Canyon. In the El Tovar region it presents the features shown in Figure 1; to the westward, however, the sandstones thicken greatly and constitute the wide shelf, or "Esplanade," which terminates in a cliff continuous with that of the Redwall and underlying Tonto beds. The following sections (Fig. 2) show the marked difference in the two regions.

MOGOLLON PLATEAU AND HOLBROOK DOME

The southeastern extension of the Arizona Plateau, known as Mogollon Plateau, extends across the southern part of Navajo County, but in Apache County it passes under the lavas of the White Mountain region. Much of the surface is Kaibab limestone, but portions are occupied by lava and Moenkopi, Cretaceous, and Tertiary formations.

FIG. 1.—Permian section in Grand Canyon near El Tovar. Looking north. *S*, Supai formation; *h*, Hermit shale; *c*, Coconino sandstone; *k*, Kaibab limestone.

From 600 to 800 feet of the red strata of the Supai formation underlie this plateau, lying on Pennsylvanian limestones to the south and east, but overlapping onto pre-Cambrian granites to the northeast. They were penetrated by borings on the Holbrook dome, and are extensively exposed in the deep trenches cut by White River and its branches, and by Cibeque, Carrizo, Cedar, and Canyon creeks. Thick limestone members in the medial and lower portions of the red strata in this region yielded many fossils, determined by G. H. Girty as follows: *Echinocrinus cratis*, *Rhombopora lepidodendroides*, *Productus cora*, *P. leei*, *Pustula nebraskensis*, *Pugnoides utah*,

Spirifer triplicatus, Composita subtilita, Hustedia mormoni, Allerisma capax?, Deltopecten coreyanus, D. occidentalis?, Myalina subquadrata?, M. perattenuata?, Monopteria marian, Plagioglypta canna?, Pleurotomaria alamillana, Phymatifer cornudanus and other forms, regarded as a Manzano (Permian) fauna.

The Supai beds are extensively exposed along White River above the Indian School and also in the vicinity of Fort Apache, with overlying Coconino sandstone in the higher slopes to the north. The usual red sandy shales and sandstones predominate, and here the thick member of limestone with Permian fossils about 100 feet below

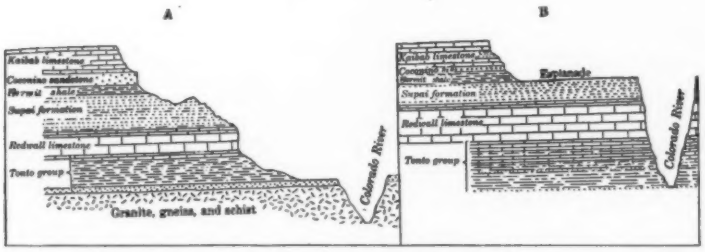

FIG. 2.—Sections of south wall of Grand Canyon showing relations of Permian formations. (*A*) near El Tovar; (*B*) near Toroweap.

the top of the formation attains its maximum development of about 110 feet, including some alternations of red shale near the top. The lower red beds are underlain by limestones containing an abundant Pennsylvanian fauna, which appear farther down White River and on Black River.

Near Ramer's Ranch (now Wallace's) near the head of Canyon Creek on the south slope of the plateau, the red sandy shales and thin-bedded red-brown sandstones of the Supai formation have the relation shown in Figure 3, which is somewhat generalized to include some nearby features. They lie on 200 feet of limestone with Pennsylvanian fossils, the top of which is exposed at the ranch. The thickness of the red strata is about 800 feet, and 200 feet below the top is the limestone member before mentioned, here 40 feet thick and containing many fossils of the Manzano or Chupadera fauna (Permian). The Supai formation is overlain by about 450 feet of

Coconino sandstone, its top beveled by the thick bowlder deposit (Tertiary) which caps part of the plateau. Not far to the eastward Upper Cretaceous strata intervene, as shown in Figure 3. The Kaibab limestone also appears farther north on the plateau, where it is exposed in deep canyons leading north.

DEFIANCE UPLIFT

In making a reconnaissance of this region in 1921 for the recently published geological map of Arizona it was found that the red beds in the central part of the Defiance uplift were unmistakable Supai for-

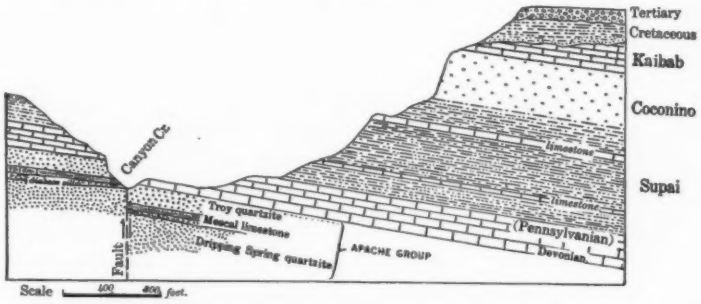

FIG. 3.—Section of Mogollon Escarpment near Ramer Ranch, Canyon Creek (Long. 110°), Gila County, Arizona.

mation lying on pre-Cambrian quartzite and granite, as in the Zuni Mountain uplift, and overlain by highly characteristic Coconino sandstone, with relations shown in Figure 4. The red rocks of the Supai formation differ considerably from Moenkopi beds, and, moreover, fossil plants collected by Case and Emery[1] in 1913 are now regarded by David White as Permian, which sustains the identification of these red beds as Supai formation, rather than Moenkopi formation of which the Lower Triassic age is established. The latter is present in the southern part of the uplift where, in the absence of Kaibab limestone, it directly overlies the Coconino sandstone, as in the region near Holbrook.

Two diamond drill borings for oil recently made by the Wilson-

[1] H. E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey Prof. Paper 93* (1917), p. 31.

Cramer Company in this uplift afford very important data as to the relations of the Supai formation. One hole, 6 miles northwest of Fort Defiance, entered granite at 114 feet, and another hole, 1½ miles east of Nazlini Store, or 18 miles southeast of Chinle, entered granite at 806 feet. In both holes typical pre-Cambrian red granite was brought up in long cores, and there could be no mistake as to its identity. The hole northwest of Fort Defiance began low in the Supai beds, while the hole near Nazlini began at the foot of a 200-foot cliff of Coconino sandstone and penetrated the following beds:

RECORD OF NAZLINI BORE-HOLE, 18 MILES SOUTHEAST OF CHINLE, ARIZONA

	Feet
Sandstone, gray, mostly cross-bedded	210
Shale, red	20
Sandstone, coarse, brown, cross-bedded	35
Red beds, mostly sandy shale, some gray alternations	541

The gray sandstone and probably also the next 55 feet of reddish beds are Coconino, and the 541 feet of red strata below are characteristic Supai formation.

HERMIT SHALE

A reference to the classification of this formation was made in an earlier part of this paper. The outcrop extends along the upper slopes of the Grand Canyon, making a slope between the cliff of Coconino sandstone above and the steps of the sandstones of the Supai below; to the westward it overlies the sandstone that makes the "Esplanade," with relations shown in B, Figure 2. The thickness of the formation is 200 feet to the east, 332 feet at Bass Canyon 20 miles west of El Tovar, 500 feet in the region west of Bass Canyon, and apparently it is thicker farther west. The last place to the south where it was observed is in the Aubrey Cliff west of Seligman, where 80 feet is reported by Noble. Plant remains comprising the fern *Callipteris conferta* collected by Noble in Hermit Basin were determined by David White as Permian.

COCONINO SANDSTONE

GENERAL RELATIONS

Throughout the Arizona Plateau region the Supai formation is overlain by 300 to 600 feet or more of massive light-gray to pale-

buff sandstone of remarkably uniform character. The only fossils so far discovered are the well-known footprints near Hermit Trail, Grand Canyon. The formation probably is absent in southern Arizona, unless represented by limestone in the Naco limestone.

GRAND CANYON AND ARIZONA PLATEAU REGION

The Coconino outcrop makes the gray band along the upper slope of Grand Canyon so conspicuous in views near El Tovar and Grand View. The thickness near the former place, where it presents the appearance shown in Figure 8, is about 300 feet, but it gradually increases to about 600 feet east of Grand View. The sandstone thins greatly to the north and west, but in the Verde Breaks it increases to nearly 1,000 feet. It is revealed in many deep canyons, notably in Cataract Creek and in Walnut, Oak, and Sycamore canyons south of Flagstaff.

WINSLOW TO HOLBROOK REGION

Thinning of the overlying Kaibab limestone and considerable up-arching in the Holbrook dome bring the Coconino sandstone to the surface at many places east of Winslow, especially in the canyons of Clear, Spring, and Chevelon creeks, and the Little Colorado River, and in the slopes south of Holbrook. The cross-bedded, buff-weathering sandstone is highly characteristic, and the borings for oil on the Holbrook dome show that at depths of 465 to 620 feet it is underlain by typical Supai formation. Moreover, it was found to extend south up the canyons and over the crest of the Mogollon Plateau, whence it was

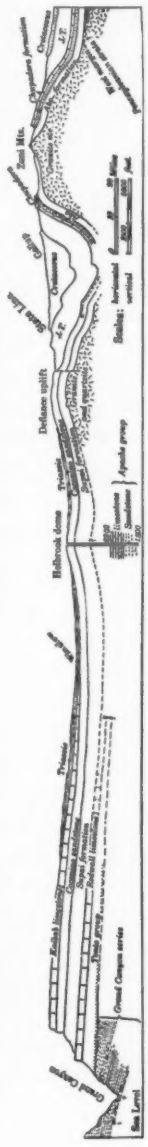

FIG. 4.—Generalized section from the Grand Canyon to beyond Zuni Mountains, across eastern Arizona and New Mexico. J.-T., Wingate-Todilto-Navajo.

traced for many miles along the Mogollon Escarpment, Verde Breaks, and Aubrey Cliffs to the Grand Canyon.

DEFIANCE UPLIFT

The truncation of the high, elongated dome extending from north to south through central Apache County exposes a large area of Coconino sandstone, a fact first brought to my attention by Mr. Dorsey Hager. The well-known Canyon de Chelly and Canyon del Muerto cut deep trenches in this formation. In the vicinity of these canyons it is directly overlain by Shinarump conglomerate, the Moenkopi formation and Kaibab limestone being absent, but from Fort Defiance southward it is overlain by red shale of the Moenkopi formation. It is about 500 feet thick, and below it, as revealed in canyons and by bore-holes, is the Supai formation which, as above explained, lies on the pre-Cambrian quartzite and granite. The structural relations in this region are shown in the cross-section, Figure 4.

KAIBAB LIMESTONE

GENERAL RELATIONS

This uppermost member of the Permian succession in Arizona constitutes much of the surface of the Arizona Plateau and it is well characterized in the detached ranges to the northwest, notably in the Virgin Mountains. It is also present in southern and western Arizona where, however, it has not yet been separated from limestones of Pennsylvanian age. As shown in Figure 4, it thins out in part of northeastern Arizona and is absent in the Defiance uplift and the northern portion of the Holbrook dome, a fact first noted by C. E. Major, a local geologist. It appears again, a few feet thick, in Moonlight Basin in Utah, at a point about 25 miles north of Kayenta. It is overlain unconformably by the Moenkopi formation (Lower Triassic). Abundant fossils in the Kaibab limestone indicate Manzano (Permian) age, but in the earlier classification it was regarded as late Pennsylvanian.

GRAND CANYON—ARIZONA PLATEAU

The plateau of Kaibab limestone extends west to the Grand Wash and Aubrey cliffs and south to the Verde Breaks and Mogollon Escarpment. The limestone is mostly of light color, and to the west-

ward a thick member of gypsum, soft sandstone, and shale is included near the middle of the formation. Although much of the Kaibab surface is eroded or covered by lava flows, the full thickness is present in places, notably where there are outliers of the overlying Moenkopi formation. In Vermillion cliffs to the north, and in the Echo cliffs and Painted Desert to the east, the limestone passes beneath the Moenkopi formation (Lower Triassic), the contact at most places exhibiting a marked unconformity which has been described by Reeside and Bassler,[1] Dake[2], Bryan,[3] and others.

The thinning of the Kaibab limestone in the northeastern part of Arizona is clearly exposed in canyons southeast of Winslow and southwest of Holbrook, and near the latter place it thins out entirely, so that the red sandy shale of the Moenkopi formation lies directly on typical Coconino sandstone. The latter is exposed in the canyons of Chevelon, Clear, and Silver creeks, and upper Little Colorado River, and at intervals on the north slope of the dome southwest of Holbrook. As explained above, several deep borings in this dome have shown that it is more than 600 feet thick and underlain by red beds of the Supai formation, so there is no doubt as to its being Coconino and not a local bed included in the Kaibab limestone, as formerly supposed.

The conditions under which the Kaibab limestone thins to the north and east, as observed in canyons southeast of Winslow, are shown in the following sections (Fig. 5); the general structure is indicated in the cross-section, Figure 4.

Near Heber are high cliffs of the limestone with Coconino sandstone at their base, while on the adjoining divides it is capped by a thin but persistent member of hard sandstone. These limestone walls continue down Black Canyon, and at a point 11 miles northeast of Heber (not far above the mouth of Pierce Draw), the top of the Coconino sandstone is capped by 125 feet of typical, gray, massive limestone of the Kaibab. Above this is an upper member of the

[1] J. B. Reeside, Jr., and H. Bassler, "Stratigraphic Section in Southwestern Utah and Northwestern Arizona," *U. S. Geol. Survey Prof. Paper 129* (1922), pp. 53–77.

[2] C. L. Dake, "The pre-Moenkopi (pre-Permian?) Unconformity of the Colorado Plateau," *Journal of Geology*, Vol. 28 (1921), pp. 61–74.

[3] Kirk Bryan, *U. S. Geol. Survey Prof. Paper 132* (1925), p. 9.

Kaibab with the components shown in Section 7 (Fig. 5). The outlier of red Moenkopi shale at the top constitutes "Red Hill."

Just below Lake Richards, in the southwest corner of T. 16 N., R. 17 E., the canyon shows 20 feet of the upper part of the Kaibab, with two included beds of gray, cross-bedded sandstone, capped by massive red sandstone at the base of the Moenkopi formation. Six miles west of this point Chevelon Canyon, about 200 feet deep, shows the beds given in Section 8 (Fig. 5).

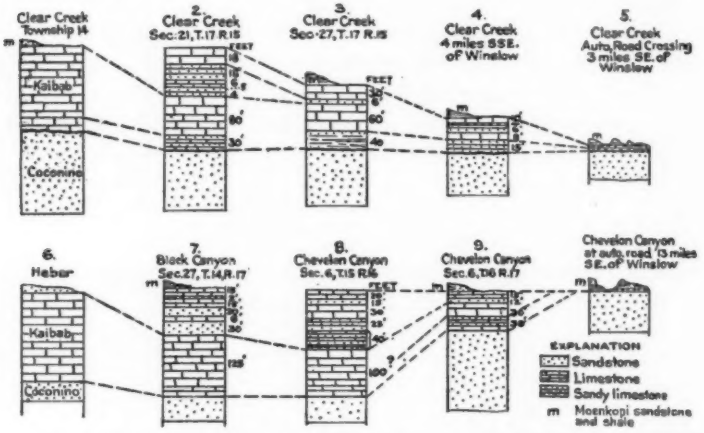

FIG. 5.—Columnar sections showing thinning of Kaibab limestone in east-central Arizona.

Eight miles farther northeast down the Chevelon Canyon, or at a point about 15 miles southeast of Winslow, Section 9 was measured, which indicates rapid thinning. In a short distance farther north the formation thins out, and at the automobile road bridge across Chevelon Canyon (Sec. 23, T. 18 N.) the basal Moenkopi sandstone lies directly on Coconino sandstone, which is excellently exposed.

In Clear Creek Canyon a similar thinning is exhibited with the various features shown in Sections 1, 2, 3, 4, and 5 (Fig. 5).

In the uplift at Crater Mound the Kaibab limestone is about 150 feet thick, with Moenkopi formation above and Coconino sandstone below. In an arroyo east of Crater Mound, crossed by the

automobile road about 11 miles west of Winslow, a 10-foot sandstone bed is exposed about 20 feet below the top of the Kaibab limestone, but the arroyo is only deep enough to expose 10 feet of the underlying limestone, which probably is about 100 feet thick. In a section 25 miles southwest of Holbrook the formation is only about 30 feet thick, including a 10-foot member of slabby sandstone at base, but it increases in thickness southward. At the extensive sinks 22 miles south of Holbrook, on the south flank of the Holbrook anticline, the rim consists of a 10-foot limestone ledge. This is overlain by Moenkopi beds and underlain by buff, cross-bedded sandstone, of which 25 or 30 feet are exposed. This sandstone resembles Coconino but it must be underlain by limestone the solution of which has caused the sinks, as there is no likelihood of salt or gypsum at this horizon. The upper part of the Kaibab limestone in the region south of the Holbrook dome consists of alternations of limestones and sandstones, the latter mostly slabby, and a few miles farther north, on the crest and northeast slope of the dome, the Kaibab limestone thins out entirely. The underlying sandstone of typical Coconino character constitutes canyon walls along the Little Colorado River near and southeast of Holbrook and extending up Silver Creek nearly to Snowflake. Near the latter place it is overlain by 3 to 6 feet of chalky rock, overlain by Moenkopi formation, and supposed to represent the Kaibab limestone. This member is also exposed in a local dome a mile southeast of Taylor, together with an underlying sandstone of Coconino aspect. The interbedding of sandstone and limestone in this region is similar to that in the Chupadera formation in New Mexico.

ABO SANDSTONE

GENERAL RELATIONS

This basal red formation of the Manzano group, generally from 400 to 800 feet thick, underlies all of central and northern New Mexico, but it thins out to the south in the southern continuation of Sacramento Mountains. Probably it underlies the eastern part of the state far below the surface, but it has not yet been definitely recognized in the well records in that region. It lies on limestones of the Magdalena group excepting in Zuni Mountains and part of the Nacimento range, where it overlaps onto the granite, and in the Pe-

dernal Mountain region, where it abuts against slopes of pre-Cambrian quartzite. Probably it has similar relations to pre-Cambrian rocks in at least a portion of its supposed underground extension eastward. The Abo-Magdalena contact is an unconformity with time hiatus of considerable length, but at most localities without noticeable deformation. Generally it is marked by sharp breaks of sediments, local conglomerates, and some channeling, but in places there is uncertainty as to the precise plane of separation, especially where red sandy members are present in the supposed top member[1] of the Magdalena group.

The few fossils collected from the Abo sandstone are Permian.

SANDIA MOUNTAINS TO SAN ANDRES MOUNTAINS

There is a long, nearly continuous outcrop zone of Abo formation extending from north to south across central New Mexico, including parts of the east slopes of Sandia and Manzano mountains, the Sierra de los Piños, the ridges east of Socorro, the east slope of the Sierra Oscura, and the western slope of San Andres Mountains. The materials are slabby sandstones and sandy shale of red-brown color, and the thickness averages about 800 feet. It lies on limestone of the Magdalena group and is overlain by Chupadera formation, into which, in the central part of the area, at least, it appears to grade through red shales with thin interbedded limestones.

ROCKY MOUNTAINS

Red sandstones of Abo aspect appear at intervals along the eastern foothills of the Rocky Mountains in northern New Mexico, where, however, there are various overlaps of younger formations. From Hot Springs, near Las Vegas, southward along the foot of Glorieta Mesa the formation is well characterized, with thickness approaching 700 feet. There are fine exposures in the deep railroad cut through the summit just west of Glorieta Station, where the formation yielded plants determined by David White as Permian. Vegetal

[1] The fossils reported by Böse east of Tularosa ("Ammonoids from Abo Sandstone," *American Journal of Science*, Vol. 49 [1920], pp. 57–60), may have been obtained from this member. Although new species, they were thought to be Pennsylvanian, but G. H. Girty informs me that even if they were obtained from Abo beds they are not diagnostic as to precise age.

material of that age was also collected farther south, near Canyoncito Station, beyond which the formation is cut out locally by faults.

NACIMIENTO UPLIFT AND CHAMA BASIN

The Abo formation is extensively uplifted in the anticline and domes of the Nacimiento-Jemez-Chama region, where it lies on the limestones of the Magdalena group, but in places overlaps onto the pre-Cambrian granite. The thickness is about 500 feet and the rocks are characteristic slabby sandstones and sandy shales of red-brown color. It was from the upper member of these beds near Coyote, 20 miles west of Abiquiu, that David A. Baldwin made a large collection of bones about 40 years ago. They were referred to the Permian by Marsh and Cope, and later examinations by Case and Williston[1] sustain this classification. They comprised *Diadectes* (Cope); *Spehenacodon* (Marsh), *Ophicodon* (Marsh); *Clepsydrops* (Cope); *Dimetrodon* (Cope); *Elcabrosaurus* (Case); *Diasparactus* (Case); *Aspidosaurus* (Williston); and *Limnocelis* (Williston). Some of these genera suggest equivalency with the lower or Wichita division of the Texas Permian, but most of them are not present in Texas. The absence of important Texas forms, notably *Naosaurus* and fish remains, and probable differences in the species indicate isolation and probably unlike environmental conditions. The latter are further indicated by differences in the character of the deposits.

ZUNI MOUNTAINS

It has been found[2] that the red sandstones and gray limestones and sandstones exposed in the Zuni Mountain uplift are the Abo sandstone and Chupadera formation, and not strata of Pennsylvanian age, as formerly supposed. The granite on which the Abo red beds lie is not post-Carboniferous, but pre-Cambrian, probably an old ridge which persisted into late Carboniferous times. In the lower Abo strata in the center of the uplift is a limestone member 30 feet thick locally, which yielded the following fossils, determined by G. H. Girty: *Composita subtilita*, *Myalina* aff. *permiana*, *Bulimorphia*

[1] S. W. Williston, "A New Family of Reptiles from the Permian of New Mexico," *American Journal of Science*, 4th Series, Vol. 21 (1911), pp. 378–98.

[2] N. H. Darton, *op. cit.*, *Bulletin 613* (1915).

aff. *chrysalis*, and *Productus*. Also fragments, probably of the genera *Schizodus*, *Pleurophorus*, *Bellerophon*, *Goniospira*, and *Naticopsis*. They are classed as Manzano.

LUCERA-LADRONES UPLIFT

The Abo sandstone is bared in the higher part of the Lucera uplift in eastern Valencia County and northeastern Socorro County. The rocks are red-brown slabby sandstones, about 800 feet thick, lying between Chupadera formation and the limestone of the Magdalena group. From basal beds southwest of Rio Puerco Station were obtained *Myalina permiana*, *M. perattenuata*, *Aviculipecten* cf. *A. whitei*, *Bakewellia?* sp., *Bulimorphia*, near *B. nitidula*, and *Spirorbis* sp., as determined by G. H. Girty, who regards them as Permian in the sense in which that term is used in the Mississippi Valley, but older than Chupadera.

MAGDALENA MOUNTAINS TO MIMBRES RANGE

The red sandstone of the Abo is exposed south of Kelly and in eastern foothills of the Mimbres or Black Mountains near Chloride and east of Fairview. A plant impression from near Kelly was determined by David White as probably of the genus *Glenopteris*, which occurs in the Wellington formation of Kansas and probably indicates Permian age.

SIERRA CABALLOS AND SIERRA FRA CRISTOBAL

Well-characterized Abo beds underlie the Chupadera formation all along the east slope of Sierra Caballos and the southeastern part of Sierra Fra Cristobal.

SACRAMENTO MOUNTAINS

The red sandstone of the Abo constitutes part of the steep upper middle-western slope of Sacramento Mountains east of Alamogordo, and a broad outcrop extends northward past Tularosa. The thickness of beds here is about 800 feet, but they thin southward, and near Owl Tank, 20 miles southeast of Oro Grande, the formation thins out entirely and the limestone of the Chupadera formation comes down onto limestones of the Madgalena group, a relation which continues to and into the Hueco Mountains on the Texas line. Whether the Abo deposits thin out or have been planed off could not be determined, but they appear not to be faulted out.

PECOS VALLEY AND EASTERN NEW MEXICO

It seems probable that Abo sandstone is present underground in eastern New Mexico north of the latitude in which it thins out at the outcrop as previously described. However, it is difficult to establish the identity of the beds in the records of deep borings, and it may be that some of the salt-bearing red beds with anhydrite and dolomite layers which I regard as Chupadera are Abo. The strata from 3,025 to 3,120 feet in the boring 13 miles north-northeast of Roswell suggest Abo, and the deeper holes farther north, especially those reaching the pre-Cambrian floor, probably passed through some Abo strata. The 2,165-foot hole 7 miles south of Lamy appears to have reached the base of Abo at 720 feet, or possibly at 1,400 feet, but it is difficult to identify the strata in the record furnished.

CHUPADERA FORMATION

GENERAL RELATIONS

A large part of New Mexico is underlain by the eastern extension of the Kaibab and Coconino deposits, which, not being everywhere separable, have been combined as the Chupadera formation. There are included also in the base of this formation some red sandy shales, probably the upper beds of the Supai formation. The formation appears to grade vertically into the Abo sandstone, with rapid change of sediments from fine to coarse, and the thin interbedded limestones in the lower part of the finer sediments are regarded as Chupadera rather than Abo. Doubtless the plane of separation varies in horizon in different parts of the area. At the top is the unconformity separating Triassic strata, which are Moenkopi formation (Lower Triassic) in the western part of the state, and Dockum group (Upper Triassic) in the eastern part, the overlap of the later group extending diagonally across all the upper members of the Permian succession in the lower Pecos River region.

The Chupadera formation appears to be absent in the northern part of the state, notably in the northern part of the Nacimiento uplift and in the Rocky Mountain region north of Las Vegas, although possibly a lower sandstone member persists.

The stratigraphy of the Chupadera formation naturally presents much variation in a region of such great size as New Mexico, but

some features persist over wide areas. Some representative sections given in Figure 6 show that the most conspicuous features are the thinning of the formation to the north, the thickening and development of salt and anhydrite in the supposed lower portion of the formation to the eastward, and the gradation into the Guadalupe group to the southward.

Among the more distinctive fossils from the limestones of the Chupadera formation are the following, according to G. H. Girty:

Lophyphyllum sp.
Echinocrinus sp.
Stenopora sp.
Derbya sp.
Chonetes aff. *geinitzianus*
Productus ivesi
Productus leei?
Productus mexicanus?
Productus occidentalis
Pustula subhorrida?
Marginifera cristobalensis
Marginifera manzanica
Pugnax osagensis var. *pusilla*
Composita subtilita
Composita mexicana
Nucula levatiformis
Euphemus subpapillosus
Manzanella elliptica
Aviculipecten aff. *vanvleeti*
Acanthopecten carboniferus?
Anisopyge inornata
Modiola sp.
Myalina aff. *meliniformis*
Myalina aff. *perniformis*
Pleurophorella gilberti?
Cleidophorus aff. *pallasi*
Pleurophorus mexicanus?
Pleurophorus aff. *occidentalis*
Schizodus wheeleri?
Bucanopsis modesta
Sedgwickia sp.
Plagioglypta canna
Bellerophon majusculus
Pleurotomaria sp.
Murchisonia aff. *terebra*
Euomphalus n. sp.
Naticopsis deformis?
Orthoceras sp.
Coloceras globulare?
Metacoceras aff. *inconspicuum*
Domatoceras highlandense?
Nautilus sp.

Few if any of these are known to occur in the Guadalupian fauna, which comprises more than 300 species, a difference which Girty[1] and Richardson[2] ascribe to differences in environment.

Bones of *Eryops*, *Sphenacodon*, etc., of Permian age were found by Case[3] in conglomerate 8 miles northeast of Socorro. They are either from upper beds of the Chupadera formation or were derived from that source in Triassic or later time.

[1] For list, see G. H. Girty, *op. cit.*, *Prof. Paper 58*, pp. 51–55.

[2] G. B. Richardson, "Stratigraphy of the Upper Carboniferous in West Texas and Southeast New Mexico," *American Journal of Science*, Vol. 29 (1910), pp. 325–37.

[3] E. C. Case, *Science*, New Series, Vol. 44 (1916), p. 709.

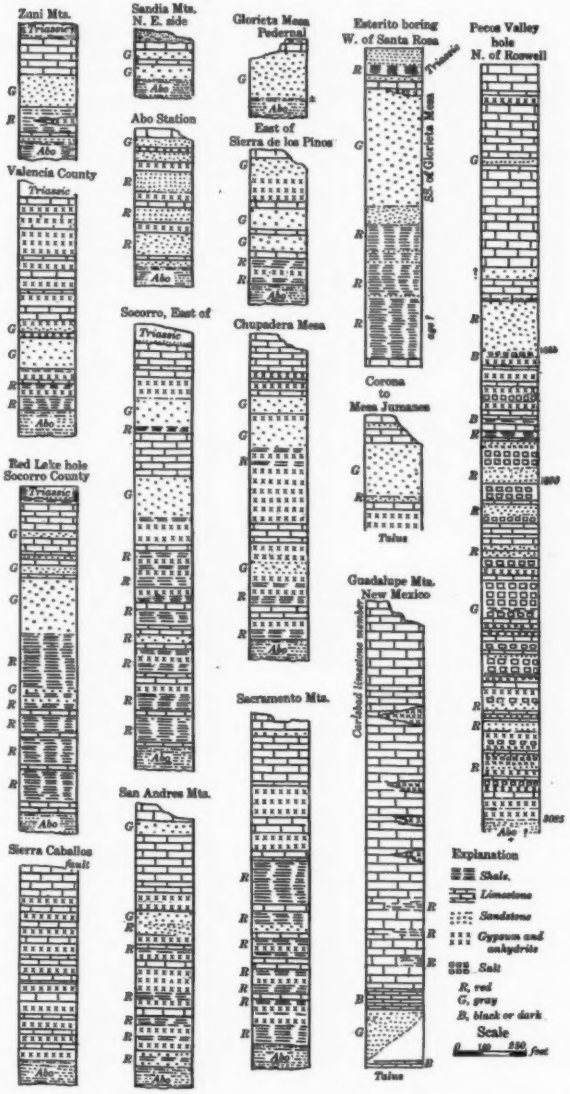

FIG. 6.—Columnar sections of Chupadera formation in New Mexico

ZUNI MOUNTAINS

The Zuni Mountain uplift reveals the Chupadera formation in a wide outcrop zone in the higher lands. It consists of limestones of typical Chupadera (or Kaibab) aspect, associated with gray, massive sandstones and underlain by red sandy shale, in all about 500 feet. The limestones and sandstones make mesas and cuestas of considerable prominence. In extensive exposures in the canyon of Bluewater River a medial member of gray sandstone is overlain by a thick upper member of gray limestone. Farther south, near the head of Zuni Canyon, underlying red sandy shales with the limestones and gypsum are exposed. A 1,980-foot boring, 30 miles southwest of Gallup, appears to have passed through Chupadera formation from 1,070 to about 1,500 feet, and then Abo strata to 1,980 feet.[1]

At a fault just south of the Indian village of Ojo Caliente, in the top of the limestone, Winchester collected Manzano (Permian) fossils determined by G. H. Girty as follows: *Chonetes* aff. *geinitzianus*, *Productus ivesi*, *P. occidentalis*, *Deltopecten coreyanus*, *Plagioglypta canna*, *Bellerophon* aff. *crassus*, *Phymatifer pernodosus* and others. Some of these species were also collected in the Zuni Mountains; they establish correlation with the Chupadera formation elsewhere in New Mexico.

SOUTH-CENTRAL NEW MEXICO

There are many exposures of the Chupadera formation at intervals across south-central New Mexico, from the vicinity of Fairview along Sierra Caballos and Sierra Fra Cristobal, in the Mesa Lucera region north of Socorro, in the uplifts east of Socorro, and in the western foothills of the San Andres Mountains. It contains many thick deposits of gypsum and has great local variation. As shown in Figures 6 and 7, there are thick massive limestone members in the upper part, and the lower members are mainly red sandy shale containing thin gypsum and limestone beds. The limestones carry a fairly abundant molluscan fauna.

NACIMIENTO MOUNTAINS

In the southern part of this range red shales and gray sandstone overlying typical Abo sandstone and overlain by Shinarump sand-

[1] The report that this hole reached granite at 1,980 feet is probably a mistake, as the Abo formation is doubtless about 800 feet thick at this place.

stone and conglomerate are believed to be Chupadera formation. The Moenkopi formation appears to be absent. Some thin limestone members are included in the sandstones constituting the upper member of the succession, but as they yielded no fossils, the correlation is not certain.

SANDIA MOUNTAIN–GLORIETA MESA–LAS VEGAS REGION

The Chupadera formation thins greatly in the northern end of the Sandia Mountain uplift, where as shown in Figure 6, it is repre-

FIG. 7.—Ridge of Chupadera formation on west slope of San Andres Mountains, east of Engel, New Mexico. Gypsum, redbeds, and sandstone capped by massive limestones. Looking west.

sented by about 125 feet of gray sandstone and gray limestones. In Glorieta Mesa the most conspicuous feature is the hard sandstone member making the steep terminal cliffs, but on the summit of the mesa 20–30 feet of the overlying limestone are present. The lower member of hard sandstone is very prominent about Bernal and was traced northward to the hot springs northwest of Las Vegas. This sandstone and the overlying limestone are exposed in Pecos Canyon west of Anton Chico, and they are brought to the surface at several places east and southeast, notably in the Esterito Dome, west of Santa Rosa. A hole on that dome appears to have penetrated Chupadera beds to 1,045 feet, but the identity of the strata at this depth

is uncertain. It passed through supposed Abo beds from 1,045 to 2,000 feet, where it reached pre-Cambrian granite.

CHUPADERA MESA AND THE MESAS FROM HILLS OF PEDERNAL TO CAPITAN MOUNTAIN

The Chupadera formation constitutes Chupadera Mesa and the long, broad tableland that extends from Glorieta Mesa past the Hills of Pedernal and the Capitan Mountain and finally merges into the cuesta of Sacramento Mountains. These mesas are capped by 100–200 feet of the greenish-gray, massive limestone constituting the upper member of the formation which thickens rapidly to the south. The lower slopes and deeper canyons expose underlying gray sandstones, gypsum, and basal red, sandy shale members. The mesas terminate in steep escarpments which are especially prominent along the west side of Chupadera Mesa (Fig. 8), in the west face of Mesa Jumanes, and in the buttes about Corona and Duran.

The ridges of pre-Cambrian rocks of the Hills of Pedernal, Rattlesnake Hills, the hills west of Pinos Wells, and Chameleon Hill, all of which rise as peaks through the formation, were islands during Chupadera deposition. In the Capitan Mountains the Chupadera strata are cut by porphyry, which has crumpled the softer beds north of Lincoln, and a similar igneous mass constitutes Gallinas Mountain and extends as a dike to Tecolote Station.

SACRAMENTO MOUNTAINS AND CUESTA

The Chupadera formation constitutes the upper part and the wide east-sloping cuesta of Sacramento Mountains. Its lower member, lying on the red Abo sandstone, consists of red sandy shale with limestones and thick intercalated deposits of gypsum. This member grades up into a thick succession of limestones which constitute the crest and long east-sloping cuesta, nearly 100 miles wide, that goes under the Pecos Valley in the Roswell-Dayton region. In the western face of the mountain below Cloudcroft many huge landslides of limestone cover the outcrop of the thick gypsum members and give the impression that most of the slope is limestone, but farther north and south the various gypsum beds are well exposed with minor members of interbedded limestone and red sandy shale. In the cuesta area the dip is low and most of the arroyos are shallow, so that it

is difficult to make a section. However, some deep holes throw light on the stratigraphy. One near Dunkin, in Sec. 29, T. 17 S., R. 18 E.,

FIG. 8.—Coconino cliff on Bright Angel trail, Grand Canyon, 300 feet high. Above are cliffs and slopes of Kaibab limestone.

revealed 674 feet of limestone, under which are sandstones, limestones, and shales to 893 feet (red, from 776 to 853 feet), and

limestones with blue shale to the bottom of the hole at 1,012 feet. At Picacho a 2,199-foot hole reported granite below 1,670 feet, "in which the drill could only progress 2 feet a day," but it is possible that this rock was an interbedded porphyry such as appears in Capitan Mountain, 20 miles south. The boring began low in the main limestone succession and penetrated beds which may be summarized as follows: 0–445 feet, shale and limestone with some gypsum; 445–530 feet, red shale and gypsum; 530–770 feet, limestone, some sandstone, and shale, with a thin red sandstone at 678 feet; 770–865 feet, sandstone, light; 865–968 feet, red beds; 968–1,026 feet, gray limestone; 1,026–1,109 feet, gray sandstone with red shale layer toward base; 1109–1580 feet, limestone, shale, and sandstone, with thin deposits of salt at 1,109, 1,158, and 1,238 feet (about 50 feet in all), and thin red beds at 1,309, 1,335 and 1,390 feet; and sandstone from 1,580 to 1,670 feet. Presumably the Chupadera formation extended to a depth of 1,580 feet with Abo sandstone below, but the upper limit of the latter may have been much higher, and some Magdalena strata may be present.

The 3,120-foot hole 13 miles north-northeast of Roswell (see Fig. 6), Sec. 31, T. 8. S., R. 24 E.,[1] appears to have been in Chupadera beds to a depth of 3,025 feet, with Abo formation below, if it is assumed that all the salt and anhydrite are in the Chupadera formation. Limestone, with subordinate amounts of sandstone, extends to 860 feet, below which is an alternation of salt, anhydrite, and dolomite with minor amounts of sandstone, in part red, 2,165 feet in all. The total salt reported is about 537 feet, and gypsum or anhydrite, about 465 feet.

GUADALUPE MOUNTAINS AND PECOS VALLEY

Guadalupe Mountains are a southward continuation of the Sacramento cuesta connected by a continuous outcrop of limestone of the Chupadera formation. Excepting some local arches, this formation presents a general easterly dip which finally carries it into the Pecos Valley, where, to the southward, it passes beneath a great thickness of Castile gypsum. In the mountains it continues southward into Texas, where it merges into the Guadalupe group, consisting of Cap-

[1] For detailed record, see N. H. Darton, *op. cit.*, *Bulletin 726*, pp. 212–13.

itan limestone and Delaware Mountain formation (Fig. 9). These two formations contain a very different fauna from that of the Chupadera formation, few, if any, of their 300 Guadalupian species being found in the latter, which carries a fairly abundant Manzano fauna. In order to study the faunal and lithologic change in this

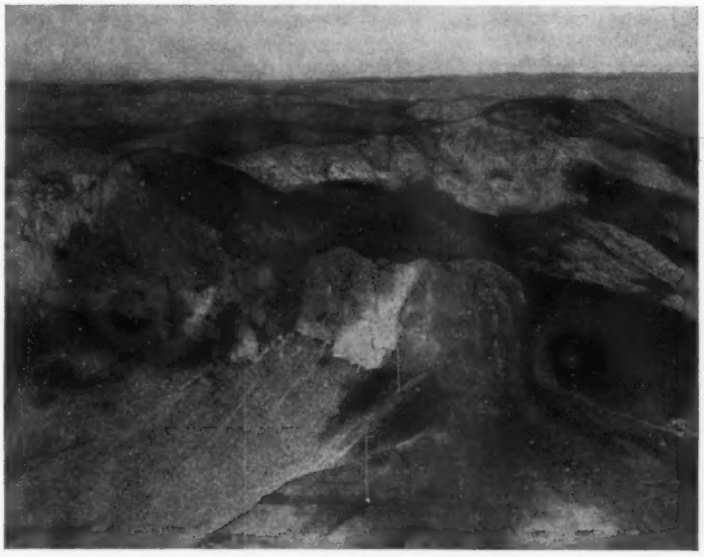

FIG. 9.—Southern end of Guadalupe Mountains, Texas. Looking north into Mexico. Guadalupe Point in right foreground, El Capitan to left. The cliffs are Capitan limestone, the slopes in foreground are sandstones of Delaware Mountain formation capped by the limestone member of that formation. Photograph by Army Air Service.

transition and to ascertain the conditions which caused it, part of the early summer of 1925 I spent in the Guadalupe Mountain region, accompanied by J. B. Reeside, Jr. The detailed results will be given in another place,[1] but some general relations are shown in the cross-sections (Fig. 10). It was found that on the west slope of the Guadalupe Mountains northward from Bone Canyon the lower limestone member of the Delaware Mountain formation thickens

[1] In publication, *Bulletin Geological Society of America*, Vol. 37.

greatly, and the 2,000 feet of overlying sandstone thins and probably disappears near the Texas–New Mexico line. Not far north, in Eddy and Otero counties, New Mexico, this lower limestone member, together with part of the overlying Capitan limestone, merges into typical Chupadera formation. There also develop to the northward thick beds of gypsum (or anhydrite) and red beds intercalated in the limestone succession. The upper half of the Capitan limestone

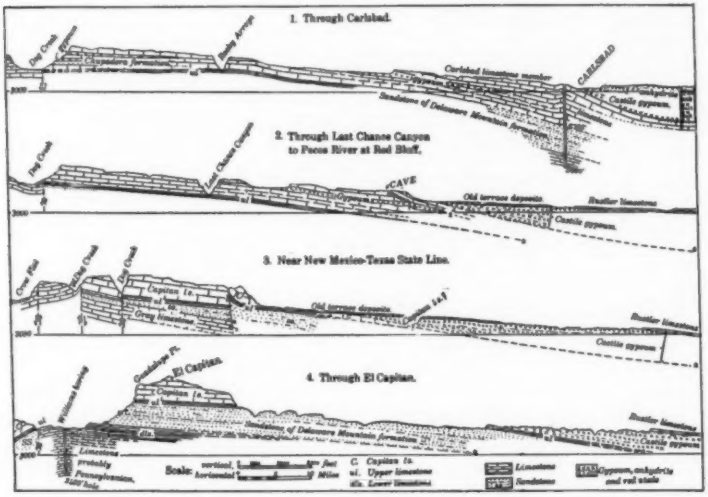

FIG. 10.—Sketch sections across Guadalupe Mountains to Pecos Valley in Eddy County, New Mexico and Culberson County, Texas.

extends northward and northeastward, where it has been named the Carlsbad limestone member[1] of the Chupadera formation, which reaches Pecos River just south of Carlsbad but thins greatly farther northeast, where it merges into red beds with limestone layers, by which it is represented in the new oil field southeast of Artesia. West of Carlsbad this member is underlain by a thick member of gypsum and red beds which thins out to the south near Queen, but extends far north along Pecos Valley, probably to and beyond Roswell, where

[1] Defined by C. B. Renick, O. E. Meinzer, and K. Bryan in a water-supply paper in course of publication by the U. S. Geological Survey.

it lies on the main body of limestone of the Chupadera formation that constitutes the northern extension of Guadalupe Mountains.

It was found that the Capitan limestone thins out very abruptly to the southeastward, for in northern Texas, east of Guadalupe Mountains, the Castile gypsum lies directly on the upper limestone of the Delaware Mountain formation as shown in Section 4 (Fig. 10). Evidently, therefore, the Capitan limestone thins out in the southern part of Eddy County, New Mexico, somewhat in the manner shown in Section 3 (Fig. 10), but unfortunately this area is covered by a thick mantle of old terrace deposits, so that the details could not be ascertained. The fact that the Carlsbad limestone member of the Chupadera formation passes beneath, and not into, the Castile gypsum is evident in outcrops near Carlsbad and southwestward, and also in deep borings east of Carlsbad as shown in the eastern end of Section 1 (Fig. 10), and to the south in Texas. The well east of Carlsbad penetrated more than 2,400 feet of anhydrite and salt of the Castile formation, and a hole (Flood No. 1), 40 miles west of Pecos in Texas, was in Castile gypsum from at least 820 to 2,148 feet. A 5,800-foot hole (see Section 1, Fig. 10) recently bored 2 miles west of Carlsbad penetrated 2,725 feet of limestone, representing the Carlsbad member and also the medial limestone of the Chupadera formation, without the thick gypsum member which intervenes to the west, and then 2,200 feet of sandstone, undoubtedly of the Delaware Mountain formation, to 4,930 feet; below which was dark limestone.

GYM LIMESTONE

In southwestern New Mexico the Permian is represented by the Gym limestone,[1] which appears in Florida Mountain, the type locality, and also in the Victorio Mountains, Cooks range, and the Tres Hermanos. Nearly 1,000 feet of the limestone remains in Florida Mountains, where it lies on Ordovician and Silurian strata, and it is 50 feet thick in Cooks range, where it lies in part on Lake Valley limestone (early Mississippian) and in part on shale of the Magdalena group. In the Tres Hermanos, where a 50-foot member of quartzite is included, the beds are much altered by porphyry. Many

[1] N. H. Darton, "Geology and Underground Water of Luna County, New Mexico," *U. S. Geol. Survey Bull. 618*, 1916, and *Deming Folio No. 207*, 1917.

fossils were found in the Florida Mountains, including *Echinocrinus ornatus*, *Productus semireticulatus*, *P. cora*, *P. occidentalis*, *Pugnax utah*, *Squamularia subtilita*, *Nucula levatiformis*, *Manzanella elliptica*, *Bellerophon crassus*, *Bucanopsis modesta*, *Rhynchomphalus obtusispira*, *Euomphalus*, sp., and *Bulomorphia inornata*.

CASTILE GYPSUM AND RUSTLER LIMESTONE

These two formations, defined by Richardson[1] in the Pecos Valley in northern Texas, were regarded as younger than the Capitan limestone. The few fossils obtained are not sufficiently definite to indicate the age, but at present the formations are thought to be Permian. They are certainly pre-Dockum and may possibly prove to be Lower Triassic. In Culberson County they lie on the upper limestone member of the Delaware Mountain formation, but in Eddy County, New Mexico, as stated above, the Castile gypsum lies on the thick limestone of the Carlsbad member of the Chupadera formation, which is a northern extension of the upper portion of the Capitan limestone. This relation is shown by many exposures and by the 2,820-foot boring 8 miles east of Carlsbad, which began in the Castile gypsum, and, after penetrating it for about 2,400 feet, passed through 400 feet of limestone and sandstone, doubtless the upper part of the Carlsbad limestone member. The strata of probable Castile formation were recorded as follows:

RECORD OF BORING IN NE. ¼, SEC. 4, T. 22 S., R. 28 E., EAST OF CARLSBAD, NEW MEXICO

	Feet
Gypsum	0– 14
Sandstone, red	14– 120
Limestone, soft (probably gypsum)	120– 175
Clay, light, sandy	175– 300
Anhydrite	300– 485
Salt	485– 618
Anhydrite	618– 650
Salt	650–1,118
Anhydrite	1,118–2,380
Limestone and anhydrite	2,380–2,490
Limestone and sandstone	2,490–2,820

[1] G. B. Richardson, *op.cit.*

A 3,705-foot diamond-drill hole 40 miles due west of Pecos, Texas, had the following record:

CONDENSED RECORD OF DIAMOND-DRILL HOLE FLOOD NO. 1, IN SEC. 42, BLOCK 54, CULBERSON COUNTY, TEXAS

	Feet
Limestone	9– 257
Gypsum	257– 270
"Conglomerate" with sandstone at base	270– 820
Gypsum (Castile) with limestone members, 1,096–1,136, 1,173–1,213, and 1,746–1,760 feet	820–2,148
Limestone, dark, some shale; 32 feet of sandstone at 2,222 feet	2,148–3,240
Sandstone	3,240–3,468
Limestone	3,468–3,705

The Troxel hole[1] at Rustler Springs revealed more than 1,000 feet of Castile gypsum, and the Huling-Ross well, 4,100 feet deep, in Sec. 16, Block 59, Reeves County, evidently penetrated 2,000 feet or more of it.

RELATIONS TO THE PERMIAN OF SOUTHEASTERN COLORADO

Very little evidence has been obtained as to the existence of Permian strata along the east slope of the Rocky Mountain front range in Colorado. Carboniferous limestone and sandstone with Mississippian and Pennsylvanian fossils are present in places, and the red beds between these strata and the Morrison formation probably contain representatives of the Permian, Triassic, and Jurassic. I have correlated some of these formations with stratigraphic units defined by myself[2] and others in Wyoming and the Black Hills, but with considerable uncertainty as to their ages.

One of the most notable sections is west of Colorado Springs,

[1] See also Udden, J. A. "The Age of the Castile Gypsum and the Rustler Formation," *Am. Journal Science*, Vol. XL (1915), pp. 151–56. He reports Foraminifera of supposed Mesozoic age from the upper 213 feet in this hole.

[2] N. H. Darton, "Comparison of the Stratigraphy of the Black Hills, Bighorn Mountain, and Rocky Mountain Front Range," *Geological Society of America Bulletin*, Vol. 15 (1903), pp. 379–448; "Geology and Underground Waters of the Arkansas Valley in Eastern Colorado," *U. S. Geol. Survey Prof. Paper 52*, 1906.

where the Millsap limestone of Mississippian age, is overlain by the Fountain[1] formation, classed as Pennsylvanian, and the Lykins formation (Triassic? and probably Permian), which extend to the unconformity at the base of the Morrison. The medial and lower portions of the Fountain formation contain Pennsylvanian fossils, but in places in the lower part of the upper member of massive red sandstone 800 feet thick, which makes the Gateway of the Garden of the Gods, there is conglomerate carrying pre-Cambrian crystalline rocks and pebbles from the underlying red beds. This member is strongly suggestive of a northern extension of the Abo sandstone, and the overlying striped red and gray softer sandstone and 150 feet of "creamy white" sandstone at the top of the formation resemble Chupadera and Coconino deposits. This light sandstone is also like the Wingate sandstone (Jurassic?) in northern New Mexico.

The Lykins formation, next above, is a thin-bedded red sandstone and shale with a thick bed of gypsum at its top; in all, less than 200 feet thick. The shale contains thin-bedded limestones suggesting the Todilto, from my southern point of view, or perhaps part of the Chugwater formation (Triassic and Permian) of Wyoming, with which I correlated it in previous years. The thick bed of gypsum, although local, is strongly suggestive of the similar bed constituting the upper part of the Todilto formation in New Mexico, as indicated by Lee,[2] quoting from manuscripts by me now awaiting publication. It may also be noted that the limestone, shale and gypsum succession at Colorado Springs is paralleled by the Chupadera succession in central New Mexico and southward, which would also be in regular order overlying Abo sandstone if the latter is represented by the upper part of the Fountain formation. However, it seems more likely that strata of Chupadera, Moenkopi, and Navajon Wingate (Jurassic) age are absent in this section, because they thin out in northern New Mexico. Lee[3] has suggested that the Sundance formation (marine

[1] G. I. Finlay, *Colorado Springs Folio* 203. He regarded the upper beds of the Fountain formation as Lyons sandstone, but W. T. Lee, in a paper now in preparation in the U. S. Geological Survey, states that this sandstone does not extend so far south.

[2] W. T. Lee, "Early Mesozoic Physiography of the Southern Rocky Mountains," *Smithsonian Miscellaneous Collections*, Vol. 69 (1918), pp. 20, 22.

[3] W. T. Lee, "Type Section of the Morrison Formation," *American Journal of Science*, Vol. 49 (1920), pp. 183–88.

Jurassic) from the north may also be represented at this horizon by non-marine beds, in which case the gypsum may be the product of a succeeding epoch of marine incursion, doubtless Todilto. The Dockum group may also be present at this horizon or lower, for in the basin of the Purgatoire River farther east I found a bone of a bolodont (Upper Triassic) in red beds under a thick bed of gypsum.[1]

RÉSUMÉ OF OVERLAP RELATIONS

In the descriptions of the various Permian formations in Arizona and New Mexico several notable overlaps have been briefly mentioned, and a summary of some of their more significant features may be of interest.

It is probable that the Permian beds lie unconformably on limestone and other strata of Pennsylvanian age throughout the Southwest, with a hiatus of unknown amount intervening. No difference in attitude of the beds was observed, and in places there is apparent gradation of sediments, but generally there is an abrupt change in material, and conglomerates and slight channeling are present. This break lies in the lower quarter of the Supai formation in the Grand Canyon (as redefined by Noble), where, however, it has not yet been noted. The break between the red strata of the Supai and the limestones with Pennsylvanian fossils in central Arizona (upper member of the Tornado limestone of Ransome) is well marked. The thinning out of the Abo formation in the southwestern part of Otero County, New Mexico, extends this unconformity high into the Permian succession, for in the Hueco Mountains Chupadera limestone lies directly on Magdalena (Pennsylvanian) limestone. Apparently this is due to thinning out of the red sediments of the Abo, but these sediments may have been deposited in this Hueco Mountain region and removed by erosion following local uplift in early Chupadera time. This unconformity will probably be found on close scrutiny.

The overlap of higher Permian beds onto eminences of pre-Cambrian rocks which were out of water in earlier Carboniferous times is well exemplified in the Zuni, Pedernal, Defiance, and Nacimiento areas, which are also zones of further uplift in post-Mesozoic or very late Cretaceous times. It is possible that earlier Carboniferous strata

[1] N. H. Darton, *op. cit.*, *Prof. Paper 52*, p. 20.

covered some of these areas originally, and were removed by early Permian erosion, but it is certain that there were ridges and shores in the Zuni Mountain, Pedernal, Nacimiento, and Defiance areas when the early Abo and Supai red beds were being deposited, which probably had persisted through earlier Carboniferous time. The precise position of these shores cannot be stated now, for the margin of rocks of the Magdalena group is not well known, and these Pennsylvanian strata overlap far beyond the edge of the Mississippian and earlier Paleozoic areas. It is not unlikely that there was also a land area of pre-Cambrian rocks in parts of central-eastern New Mexico during early Permian time, for a preliminary map of the "bed rock" in that area shows diversified configuration and possible absence of Pennsylvanian rocks in areas of considerable extent.

The thinning of the Kaibab limestone in the Defiance uplift probably indicates considerable uplift of that region between the Coconino and Kaibab times, for the strata appear to thin out and not to have been planed off by early Triassic erosion. The absence of Lower Triassic (Moenkopi) in the northern part of the uplift doubtless indicates a persistence of the uplift in that area until the time of Shinarump deposition.

The thinning of the Chupadera formation to the north so that it disappears in northern-central New Mexico is an interesting detail of overlap, and the change from Chupadera character and fauna to the Guadalupian in southern Eddy County indicates a great change in environment in that direction. Just how the Castile and Rustler depositions fit into the subsequent chronology is also a problem. It is clear that the Permian-Triassic unconformity is very general, and the Lower Triassic sediments appear to be absent east of the Rio Grande, unless possibly they are represented by the Castile and Rustler strata.

OBSERVATIONS ON THE OCCURRENCE AND ORIGIN OF PETROLEUM IN ARGENTINA AND BOLIVIA[1]

ROBERT ANDERSON
Menlo Park, California

ABSTRACT

This paper, based on observations in 1917, outlines the geographic and geologic range of petroleum indications in Argentina and the Atlantic watershed of Bolivia, and discusses the probable mother-rocks. Besides the Comodoro Rivadavia field on the Atlantic coast of Patagonia, where petroleum is produced in quantity, seepages and other evidences of oil are scattered along a sub-Andine belt over fifteen hundred miles long from southwestern Argentina to north central Bolivia, and range through many thousands of feet of the sedimentary series. The original sources appear to be sediments containing organic remains in formations of widely different ages, ranging from Devonian to Cretaceous. The chief source beds are here postulated as being the marine Devonian and Cretaceous in the northern Argentine-Bolivian belt; fresh or brackish water Upper Triassic near Mendoza; marine Upper Jurassic-Lower Cretaceous in southwestern Argentina; and marine Cretaceous or older beds on the Atlantic Coast.

INTRODUCTORY

The author of this paper enjoyed the privilege of journeying over much of Argentina during the year 1917, and likewise made trips into the southern portions of Bolivia and Brazil. The geologic work which affords the basis for this paper was in the nature of reconnaissance. The paper is intended merely to outline the distribution of the indications of petroleum and to present a few observations from the geological point of view as to its possible original sources.[2]

PETROLEUM-BEARING REGIONS

The main regions of Argentina and Bolivia in which there are strata known to contain traces of petroleum are the following:

[1] This paper was presented to the First National Chemical Congress in Buenos Aires in 1918, and, with certain modifications introduced at the time of its translation into Spanish, was published as a pamphlet, in Spanish, in 1919, jointly with a paper by Dr. Ernesto Longobardi (Buenos Aires: Establecimiento Grafico T. Palumbo, 1919). Published with the kind permission of Messrs. S. Pearson & Son, Ltd.

[2] The writer desires to acknowledge his indebtedness to the geologists and publications of the Argentine government for much helpful guidance, and in particular to Dr. Guido Bonarelli for the information and assistance which he generously gave.

1. The Salta–Santa Cruz region, forming a belt over a thousand kilometers in length running northward from the southern part of Salta Province, through Jujuy Province, to or beyond Santa Cruz in Bolivia.

2. The Mendoza–San Juan region, extending about 200 kilometers from the Cacheuta field in northern Mendoza Province northward into San Juan Province.

3. The Neuquen–Mendoza region, running from the southern part of Neuquen Territory some 600 kilometers northward to the central part of Mendoza Province.

4. The Southeastern Chubut region, comprising the Comodoro Rivadavia field and adjacent districts.

The geographical position of the first three regions is analogous, as they lie along the pre-cordillera, or the borderlands between the Andes and the Pampas. The fourth region is quite distinct in belonging to the Atlantic coastal belt. Geographically each region presents characteristics that give it individuality.

OBSERVATIONS ON SALTA–SANTA CRUZ REGION

In the region of Salta, Jujuy, and southern Bolivia traces of oil occur at various horizons scattered through a succession of strata thousands of meters thick. This succession may be outlined as follows:

Devonian.—The oldest petroliferous beds comprise a thickness of 300 meters or more of Devonian marine shale and sandstone, which is impregnated with oil for a distance of several hundred kilometers in southern Bolivia. The same formation extends southward into Argentina beneath the series known to be oil-bearing there, and while petroleum indications have not hitherto been found in the Devonian of Salta and Jujuy, the writer is of opinion that careful search will probably reveal such traces.

"*Lower Sandstones.*"—The series overlying the Devonian comprises a thickness of over two thousand meters, mainly of sandstone, conglomerate, and shale, which may be grouped under the name of "Lower Sandstones."[1] Exudations of oil occur at numerous places from various horizons of this series.

[1] The subdivisions and names here used are those adopted for convenience by Bonarelli.

The question of the age and origin of the "Lower Sandstones" is puzzling, since no fossils have been discovered in them. They were probably deposited in part in the sea and in part on the land. The most likely supposition as to their age is that they range from the late Carboniferous or the Permian up into the Mesozoic. Certain gritty and conglomeratic clays and sandstones somewhat resemble glacial deposits and suggest a possible glacial origin. In the opinion of the writer the series is in whole or in part the equivalent of the Permo-Carboniferous "Paganzo" series of the Mendoza–San Juan region, and also of the Permian glacial and at least partially marine series of southern Brazil.

"*Dolomitic Limestone.*"—A very persistent formation that marks the top of the "Lower Sandstones" is a distinct zone of calcareous and siliceous shales and sandstones containing minor beds of dolomitic and flinty limestone. This zone ranges in thickness from 20 up to about 200 meters. In two or more districts in Jujuy it is petroliferous. The formation is of marine origin, contains a few fossils, and is usually—although not conclusively—ascribed to the Cretaceous.

"*Upper Sandstones.*"—The zone just mentioned is overlain by a few hundred meters of beds consisting mainly of reddish sandstones. Locally they have a basal conglomerate full of fragments of the underlying "Dolomitic Limestone" zone and apparently indicating an important unconformity. These "Upper Sandstones" have yielded no fossils and their age and origin are in doubt. In a few places their outcrops are impregnated with oil.

"*Sub-Andine Tertiary.*"—The sandstones just mentioned grade imperceptibly upward into a huge series, at least three thousand meters thick, composed predominantly of reddish-brown, rather soft and earthy-looking sandstone and clay. This series is also barren of organic remains as far as known. Its age and origin are therefore likewise in doubt, but the presumption is in favor of considering it mainly of Tertiary age, and non-marine. Traces of petroleum are reported at one or two points in, or close to, its base.

Probable source of the oil.—Two formations in the Salta–Santa Cruz region may be considered potential sources. These are the Devonian and the "Dolomitic Limestone" zones. The other strata

are predominantly sandy, are lacking in traces of organic material, and, so far as present knowledge goes, they show no features that can be conceived of as likely to generate petroleum.

The Devonian contains fossil remains of marine crustaceans, mollusks, and other animal organisms, as well as impressions of both land plants and seaweeds. It is noteworthy that this formation is a fairly near-shore marine deposit and has undergone very little disturbance and alteration during the long period since it was laid down. The zone of calcareous and siliceous shales referred to under the name "Dolomitic Limestone" evidently contained a large amount of organic remains at the time of its deposition, even though the traces of these have been largely obliterated. The principal elements of the latter appear to have been marine mollusks, and probably an abundance of foraminifers and other minute organisms. The Devonian formation is more consistently petroliferous than any other horizon, contains the largest seepages, and underlies the whole region, whereas the "Dolomitic Limestone" is known to be oil-bearing only in the province of Jujuy. It is likely, however, that petroleum originated in these later beds as well as in the Devonian, and the heavy, asphaltic nature of the oil in the Jujuy seepages gives support to a theory of distinct origin from that of the lighter oils. Two extreme types of petroleum are observable, a very light, yellowish, kerosene-like oil in Bolivia and northernmost Argentina, and the heavy black oil of Jujuy. Between these types there are various intermediate grades, which may probably be accounted for by the varying degrees of migration, filtration, and evaporation that the petroleum has undergone.

OBSERVATIONS ON MENDOZA–SAN JUAN REGION

The petroleum indications of the Mendoza–San Juan Region occur principally in the Rhaetic formation. This consists, in the main, of several hundred meters of shale and fine sandstone. Much of the shale is characterized by a marly and siliceous composition, papery texture, and other features common in shales that are believed to have given rise to petroleum in some other petroliferous districts of the world. The formation contains an abundance of

plant remains, principally ferns and cycads, and great numbers of a small Crustacean called *Estheria*. It also contains traces of a ganoid fish. An occasional occurrence of oölite and the character of the shale suggest that minute organisms such as Foraminifera and possibly diatoms entered into its composition.

The Rhaetic formation outcrops in several isolated areas, and almost always shows signs of containing, or having formerly contained, petroleum, whereas the associated rocks are for the most part barren of such indications. The formation thus gives a very strong indication that the oil originated within it. It is likely that the material of the plants and minute organisms inclosed within the sediments afforded the chief source of the hydrocarbons. The animal matter may have contributed also.

This Rhaetic formation of Mendoza has heretofore been considered as laid down in a fresh-water lake. If that be the case, it is one of the rare instances of the probable origin of oil in a fresh-water deposit. In the opinion of the writer, however, it seems more probable that the sediments were deposited in a brackish-water lagoon connected with the sea, although there is not necessarily any reason why oil should originate in marine formations alone, as some believe.

In addition to the petroliferous Rhaetic beds, it appears from Stappenbeck's description that at various points beds in the Permo-Carboniferous ("Paganzo") plant-bearing series are bituminous. These bituminous layers are usually described as marly. The conclusion to be drawn from these occurrences seems to be that at least a little petroleum was formed in the plant-bearing and marly beds of the "Paganzo" as well as in the Rhaetic. Both these formations contain local coaly layers, which illustrates how the plant remains locally make up a considerable proportion of the volume of some of the beds.

OBSERVATIONS ON THE NEUQUEN-MENDOZA REGION

A score or more of seepages or other traces of petroleum occur in the Jurassic and Cretaceous strata of the sub-Andine region from central Neuquen for a distance of some 600 kilometers northward

into central Mendoza. Some 300 kilometers farther south traces of oil also occur in Rio Negro Territory, in beds supposed to be of Cretaceous or early Tertiary age.

So far as observed by the writer in the Neuquen region, the vertical distribution of oil indications is through less than a thousand meters of beds, and the main horizon is in the marine formation of marls and sandstones to which an Upper Jurassic and Lower Cretaceous age is ascribed. This formation contains an abundance of marine fossils. Its beds are the only ones cropping out that appear at all competent to have formed petroleum, and they probably constitute the original source. The Rhaetic beds of the Mendoza–San Juan region are apparently absent here.

OBSERVATIONS ON THE SOUTHEASTERN CHUBUT REGION

In the Comodoro-Rivadavia field petroleum does not appear at the surface, but is found at a depth of a few hundred meters in sandy beds supposed to represent part of the Upper Cretaceous. The surface of the field is covered by a thick formation of marine Tertiary beds (Patagonian). This is underlain by about 350 meters of unfossiliferous clay, and this in turn by a marine fossiliferous formation, about 200 meters thick, of greenish glauconitic sands and clays containing some petroleum. The latter formation is believed to be of Upper Cretaceous age. Beneath are the main oil sands, which are without fossils, but which are thought to be likewise Upper Cretaceous in age.

It is a matter of speculation as to what may underlie these oil sands. The opinion usually expressed is that the formation in which they occur rests upon the porphyries, which outcrop at distant points along the coast. The writer, however, believes that the region will be found to be underlain by older sedimentary beds, probably corresponding to some of those that are oil-bearing in the Andean region, and that the origin of the petroleum is to be sought in such older strata. It is likewise a possibility to be considered that some or all of the oil of the Comodoro-Rivadavia field originated within the series so far penetrated by the wells, namely, in the fossiliferous marine Cretaceous deposit mentioned. This formation contains many small shells and a minor admixture of Foraminifera which may

have contributed to the oil, but the source hardly seems an adequate one.

GENERAL REMARKS ON THE ORIGIN OF THE PETROLEUM

From the preceding review it will be seen that evidences of petroleum appear in strata of many different ages, ranging from the Devonian to the Cretaceous or even Tertiary. This fact is contrary to the opinion which has heretofore gained some currency, that the oil occurs only in the Mesozoic rocks of this portion of South America. In particular the oil-bearing strata in the Salta–Santa Cruz Region have been repeatedly referred to as Cretaceous by the German geologists, and it is interesting to note that their so-called "Cretaceous" *Formacion Petrolífera* in fact includes deposits of various ages from Devonian to Cretaceous or Tertiary, and that in southern Bolivia, at least, the Devonian formation is the prime oil container. The occurrence in the Devonian gains additional interest, although perhaps no special significance attaches thereto, by reason of the fact that the North American Devonian strata, rich in remains of organic origin, contain indications of petroleum and have probably been a source of it over a vast region in the northern part of that continent.

The great majority of the petroleum seepages and bituminous outcrops in the Argentine and Bolivian regions already outlined, as in other regions of the World, occur in stratified sediments, away from any possible igneous influence. Anyone who studies their geologic occurrence and relations must concede that the oil originated within the sedimentary deposits themselves, from organic material originally included in the strata.

MICROTHERMAL OBSERVATIONS OF SOME OIL SHALES AND OTHER CARBONACEOUS ROCKS

TAISIA STADNICHENKO[1] AND DAVID WHITE
National Research Council, Washington, D.C.

ABSTRACT

These experimental studies are planned (1) to show whether the various fossil constituents in an oil shale or other carbonaceous rock are characterized by differences in their chemical constitution that will result in differences in the temperatures at which they volatilize or undergo change of state; (2) to determine whether and how far the same kinds of fossil constituents react at the same temperatures in shales more highly carbonized by natural processes; (3) to secure such information as may be gained by the same methods as to the stages of carbonization at which the various fossil components fail to give evidence of chemical distinction; (4) to show what physical constituents of the "shale" yield oils or other condensible distillates by heat treatment; and (5) to secure data for the determination of the proportions and qualities of the distillate (with inferences as to natural oils) that are derived from one fossil commodity or another.

The methods are new and are not yet fully developed and the experimental results are but partly interpreted. For the completion of objectives 4 and 5, above listed, retort distillations of check samples and chemical examinations of the products are required to supplement the microfurnace observations.

INTRODUCTION

These studies have for their immediate objects the observation and determination, by means of a microfurnace, of the temperatures at which the optically distinguishable fossil components and their derivatives in the varied organic conglomerates that make up the different types of bituminous shales, "oil shales," and other carbonaceous rocks undergo changes in optical character, volume, and state of matter, some of which changes are incidental to chemical change.

Oil shale—its nature.—The microscope shows that bituminous shales, or oil shales, and related sedimentary deposits, including bogheads, "kerosene shales," and cannels, are agglomerates differing both as to sources of the ingredient organic bodies and products, and as to their original chemical composition. The visible ingredient organic constituents in the rock consist, for the most part, of portions of plants and animals that were originally of such composition and

[1] Instructor of chemistry, Vassar College, Poughkeepsie, N.Y.; research assistant, Petroleum Geologists Fund, National Research Council.

structure as to resist complete decay when deposited in the muds or other rock-forming sediments. The remainder of the organic matter associated with and enveloping the plant and animal débris consists of the products of the decay, or partial decay (biochemical), of dead organisms.

Viewed from the paleontological standpoint, the four principal kinds of organic matter present in oil shales and other supposed mother-rocks of petroleum are: (1) the "ulmic" binder or "groundmass"; (2) spore and pollen exines; (3) cuticles and cuticular secretions; and (4) algae that are more or less fatty, or oily.

1. The "binder" or "groundmass" is composed of products of the more or less complete biochemical decomposition of different kinds of plant and animal matter. These biochemical products, together with the most minute attritus, are at first held in colloidal solution in the water, but later, under pressure of superimposed strata, subjected to incipient progressive alteration, they become gradually solidified (dehydrated) into a dense residue, generally brown or brownish-black, which surrounds and cements the organic and inorganic detritus. This decomposition solution, which is generally referred to as "ulmic," or "humic," or "ulmo-humic," should, and probably does, vary somewhat in composition from one type of oil shale to another, according to the conditions of decomposition and the kinds of initial ingredient matter. The "ulmic" binder may comprise a considerable part of a mother-rock composed largely of organic débris, or it may appear as a translucent yellow or brown cement in a rock largely made up of inorganic mineral sediments.

2. The waxy-fatty, or resin-waxy, outer coverings (exines) of spores and pollen grains of different kinds belong to all orders of plants, and differ somewhat in chemical composition according to kind. In general composition they are oily or fatty, waxy, or resinous, and are most resistant to decay in water. All are characterized by relatively large proportions of hydrogen and relatively small proportions of oxygen. They are omnipresent in oil shales and coals, though differing greatly in relative number.

3. Fragments of cuticle, or the protective skin, or integument, of such parts of the plant as stems, petioles, stipes, fronds, and thalli, that are made resistant to decay under water by the secretion

of resin-oily, horny, waxy, or resinous matter, even when most other parts of the plant or tree have decomposed, are always present in varying proportions. With the cuticular residues may be classed, as related thereto, although chemically differing, fragments and scales of waxy matters and pigments secreted on the stems and leaves, or in the tissues, of plants. The waxy constituents, which, as is well known, differ among themselves in composition, are higher in hydrogen and lower in oxygen even than the exines.

4. The more richly bituminous deposits include varying amounts of the remains of algae containing waxy, oily, or fatty matter. Many of these belong to types in which was secreted such special matter as thickening of cell walls. This material was relatively resistant to decay in stagnant water. These algae, among which microscopical one-celled forms growing united in colonies are most characteristic, may be entirely absent; they may be sparsely scattered among the spore exines and cuticles of canneloid layers of coal, or in cannels; or they may be present and preserved in such incredibly large numbers as to constitute the greater part of the organic matter. The bogheads, richest of all the oil shale series, are made up almost entirely of such algae. In the microscopical section they appear as golden, or lemon-colored, bodies, often showing the complete details of their plant structure, immersed in the dark brown "ulmic" decomposition groundmass.

5. Other fossil débris, generally less important as constituents of the deposit, may occur in one oil shale or another. Fragments of resin of different kinds, mostly in the form of particles generally microscopical in size, may be present in considerable numbers, being, in fact, concentrated in the deposits by the decay of resinous wood. Small fragments of the more resistant woody tissues of plant or tree are occasionally found, though usually sparsely, in the form of shreds or ragged pieces impregnated by the "ulmic" solution, or as fragments of so-called "mineral charcoal," or "mother of coal" (fusain). Horny or osseous and consequently resistant parts of animals, such as scales, teeth, spines, or bones, may be present; and the skins, wings, and egg coverings of insects and Crustacea, which are chitinous and therefore of a most decay-resistant organic composition, also are locally present.

All the types of fossil organic remains named above may be present in a cannel and even in an oil shale, but so wide a representation in a single section of shale is very rare. In most of the oil shales and similar carbonaceous rocks, one or another of the four principal kinds of organic matter first mentioned predominates. Spores (exines) always predominate in the cannels and canneloid types of rock, with varying but smaller amounts of resin, or cuticles, or both. Exines and cuticles may be prominent in some oil shales, though in others cuticles, or more rarely, even exines, are very scarce. Algae are more characteristic of the typical oil shale, and may be very abundant, though, due to lack of preservation, they appear to be wanting in some cases. Ulmic matter is always present, and stray resin grains are found in most carbonaceous deposits that are not too far altered.

Statement of the problem.—Although the various kinds of vegetable débris differed widely in chemical composition at time of deposition as sediments, and even the so-called groundmass may reasonably be believed to have at first differed somewhat from one type of oil shale to another, the present chemical constitution of these paleontological components is still almost unkown. It remains to be seen to what extent the plant vestiges of different types in any given rock preserve their original chemical characters and distinctions; whether they are more or less altered differentially; whether they are wholly altered, yet are chemically distinguishable from stage to stage in the progress of carbonization; or whether, either as the result of diffusion and replacement by "coalifying" substances, generally grouped under the term "ulmins," toward which the vegetable tissues may have acted as semi-permeable membranes, or, as the result of the alteration (carbonization) of the deposits as a whole, the organic débris is now chemically homogeneous. Both, from the aspect of the fossil débris in the thin section and from the study of the progressive evolution of the carbonaceous deposits as viewed from the physical and gross chemical standpoints,[1] it would seem fairly certain that many, at least, of the initial chemical differences due to the ingredient matter and the conditions of deposition, should

[1] W. H. Twenhofel, *et al.*, *Treatise on Sedimentation*, Baltimore, Maryland, 1926, p. 304.

carry over in varying degrees into the consolidated sedimentary rocks, and should account for some of the differences in the chemical composition not only of the different deposits, but also of the distillates derived respectively from them.

If the different visible organic constituents of the carbonaceous rocks differ in their composition (whether as inherited or subsequently modified), it is evident that they should behave more or less differently when subjected to heat distillation, each type yielding products of correspondingly more or less distinct and characteristic chemical composition. Obviously, also, the composition of the distillate (itself an aggregate) obtained from the rock aggregate should be determined largely by the kinds of ingredient matter in the rock and the relative proportions contributed by each kind. It is known, for example, that the distillates from rocks, such as bogheads and torbanites, which are made up largely of the fatty, oily, or waxy algae (their real composition is not yet known) are in general not only much more voluminous than those yielded when other constituents predominate, but they are more valuable, being of lighter gravity, usually with more saturated hydrocarbons. On the other hand, the yield by distillation of shales containing more cuticular matter or larger numbers of resin grains, is inferior in quality and generally in quantity. Increase of tarry residues, with probable decrease of volume of distillate, accompanies the inclusion of woody (originally carbohydrate) vestiges.

What are the products which are actually yielded by the different constituents, such as algae, exines, cuticles, mycelia, or groundmass, in any given sample of shale when it is distilled? Or, conversely, what qualities or elements in the distillate originate from each of these sources when the rock is subjected to heat decomposition? What are the temperatures at which any one of these materials breaks down, with evolution of condensible volatile hydrocarbons, and with possible further generation, at a later stage, of additional and different products when the residue is heated to some higher degree? No one knows definitely, or even approximately, the rôle played by any single ingredient of the rock in determining the type or qualities of the distillates or the temperatures at which they are generated; the respective causes and effects are neither identified nor correlated.

In brief, the primary problem is to determine the relations between the components of the organic agglomerate forming the shale or other mother rock, and the amounts and qualities of the oils obtained either by distillation or by geologic processes.

The experimental observations, of which this paper is the initial report of progress, aim at the accurate determination of the temperatures at which melting, boiling, and volatilization, or visible changes in color, volume, aspect, or action take place in the fossil ingredients and groundmasses of the different mother-rocks when thin sections of the rocks are heated in an inert atmosphere in the microfurnace. At the same time they bear critically on the question of distinctions in chemical composition between the kinds of débris in any given rock, and in different rocks, and in the same rock at different stages of carbonization.

According to the plan in view, in which this study is the first stage, the microthermal observations should be followed by distillations of the same rocks under the same conditions in a special retort, so that test cuts may be taken off at the temperatures corresponding to the observed changes in the constituents noted under the microscope. The detailed chemical study of these cuts, the third stage in the procedure, should not only throw invaluable light on the importance of each of the readily visible constituents in the rock and of the organic groundmass as sources of distillates generated under different processes or conditions, but it should also indicate, roughly at least, the quality of the distillate (the hydrocarbon compounds) yielded by each. Joined with the microfurnace and the retort tests, it should go far toward tracing the qualities as well as the quantities of the distillates back to their organic sources. Through analogy and inference, a better understanding may be reached of the origin of the natural petroleums also, and of the relations between the characters of the oil and the characters of the mother-rock. Collectively, the studies should aid in opening the door to the attack, from the genetic standpoint, on the fundamental chemistry of petroleum.

AUSPICES OF THE WORK

For some years the authors have become more and more convinced that important light might be thrown on the problems of the composition of the carbonaceous rocks and of the origin of oil by

observing the organic substances present and readily differentiable to the eye while they were heated under close control in an inert atmosphere under the microscope, so that the physical changes taking place in the thin section might actually be seen. Through the interest and co-operation of the Carnegie Geophysical Laboratory, four microfurnaces have been designed and constructed in that laboratory. Though all have been successful, the later designs have given most promising results. Grateful thanks are due to Dr. A. L. Day, director of the Laboratory, and especially to Mr. H. S. Roberts,[1] physicist, and Mr. Charles J. Ksanda, mechanician, for the production of a working furnace permitting the use of a 16-millimeter objective.

A grant of two hundred dollars, made by the American Association for the Advancement of Science in 1923, helped to defray a part of the cost of experimental equipment at the outset. Later the project aroused the interest of a number of geologists of the American Association of Petroleum Geologists who are funding the studies for the current year through the Research Committee of the Association and the National Research Council. Helium and liquid air have been furnished through the courtesy of the U. S. Bureau of Mines, and storage battery, optical equipment, and other laboratory facilities have been made available by the U. S. Geological Survey. The authors are grateful to these co-operating agencies and to the Bureau of Standards and the Committee on Exhibits of the National Academy of Sciences for their friendly good offices.

METHOD OF PROCEDURE

All rocks examined were cut in sections ground to a thinness of 4–8 microns by Mr. Frank Reed in the laboratory of the Geological Survey. To avoid the use of solvents or heat, necessary when hard Canada balsam is used, the sections of oil shales were generally mounted in fresh sodium silicate which afterward was removed by dissolving in warm (about 40° C.) distilled water, after which the section was washed carefully and kept quiet under distilled water until used in the heating experiments. Particular care was taken to

[1] See papers from the Geophysical Laboratory, Carnegie Institution of Washington, No. 563.

avoid heat in grinding, and even those sections mounted for permanent preservation in balsam were not allowed to be warmed above 100° C., for it was soon observed that volatile matter is lost by some of the carbonaceous rocks when heated slightly beyond this point.

Ordinarily a small fragment less than 5 mm. square is cut from a thin section for examination in the furnace. It is then placed between dried slides of fused silica and dehydrated with alcohol, after which the slides are quickly transferred to the microfurnace, from which air is immediately pumped by an electric "high vacuum" pump. Helium is then fed through the air-tight furnace for 10–20 minutes before the furnace is heated and the observations begin. Nitrogen might be used, but it is likely to enter into combination in some of the compounds generated in the furnace.

The furnace, built in the form of a vertical cylinder, rests in the stage ring of the microscope. The resistance may be wound about a central vertical core, or a flat stove, into which the quartz glass slides are inserted. Both types have been used. Quartz glass windows are fixed in the top and bottom of the furnace, both ends of which contain water-cooling rings. A nipple outlet permits helium conservation. The thermo-couple, of platinum-rhodium and gold-palladium wires, is used.

The furnace now most used permits the employment of a long angle "two-thirds" Swift and Sons objective. A Leitz microscope with the improved type of the Edinger projection stand projects the image onto a horizontal surface where, besides being watched with ease, it may be traced or photographed from time to time.

Great precaution must be taken to escape partial or entire oxidation of the section by extraneous oxygen within the furnace. Exasperating difficulty was encountered and much time lost during early months of the work on this account. Any oxygen which may remain in the helium is removed by passage through a heated tube filled with copper gauze, after which, as a double precaution, it is run through two U-tubes filled with cocoanut charcoal set in beakers of liquid air. At this temperature charcoal absorbs all gases except helium. However, oxidation still took place occasionally in spite of these precautions, until the baffling situation was in general successfully met by the removal of the air films from the quartz glass

slides and the prompt exhaustion of the alcohol-filled dead air space 8–3 microns thick, between the slides, as described above. The oxidation, which is quickly detected by the experienced eye, is clearly selective, thus showing differences in the composition of the organic débris.

NOTES ON SOME TESTS OF OIL SHALES AND CANNELS

Since the studies are now only in the initial stage, this paper is merely a report of progress, in which are presented (1) the objectives, technique, and plan of the work, mainly for the interest of other students; (2) a few exemplary tests; and (3) some conclusions already apparent.

The observations as yet made are but partially interpreted. In fact, although inferences may in some cases be drawn with probable safety, and sometimes with certainty, interpretation of many of the changes observed in the organic matter will be possible only in the light of future experience, or when the microfurnace study will have been followed by the distillation tests to be made of the same rocks in the retort, and these in turn are subjected to chemical analysis. The presentation of tables and graphs is deferred to a later report, to be based upon a larger series of records.

To date the examinations cover a number of oil shales of different ages and types, and the same type of rock at somewhat different stages of carbonization; also several cannels, and some carbonaceous shales, together with a few coals and bogheads.

The following outlines of four experiments are given, not so much by way of presentation of information gathered, as to illustrate some of the observations made on different types of carbonaceous rocks. Undoubtedly, with further development of technique and experience in their study, data more accurate, more detailed, and of greater value will be brought to light.

Australian oil shale.—The material first studied was a very pure boghead, the so-called "kerosene shale," of Permian age, from the Wolgan Valley, Newenes, New South Wales. The physical and chemical characters of this type of rock are described in the *Memoirs of the Geological Survey of New South Wales*.[1] In its purest state it is

[1] J. E. Carne, "The Kerosene Shale Deposits," *Dept. of Mines and Agriculture, Memoirs of the Geol. Survey of New South Wales, Geology, No. 3*, Sydney, 1903.

found to be made up almost entirely of compound colonies of the one-celled alga, referred to the Protococcales, which was described by Renault[1] under the name *Reinschia australis*. The algal nature of these colonies, put in question by Jeffrey,[2] who regards them as spores, has recently been confirmed by Thiessen,[3] who describes similar organisms living today in alkaline waters of South Australia where they form bituminous deposits (coorongite) distinctly fatty in composition and capable of yielding distillates in relatively large amounts.

The Australian boghead is an algal coal resembling a massive cannel. In the purer beds, which may yield as much as 140 gallons of distillate to the ton, the algal colonies, which almost wholly compose the rock, sometimes appear suspended merely in contact in the homogeneous dark brown "ulmic" concentrate of biochemical origin, which forms the groundmass. The largest compound colonies are almost large enough to be seen by the naked eye.

When the thin section of this boghead is heated to 180° C., some loss of volatile matter appears to take place and the colonies assume an aspect of relief. At about 225° the inner structure of the algal colonies is better defined, the cells becoming more distinct, and in some instances the cell wall is clearly differentiated from the "ulmic" cell contents. The aspect of the section changes but slightly through a following rise of more than 100° in temperature, beyond which, at about 326°, the colonies are very brilliant lemon-yellow in the groundmass, which is of a warm reddish hue.

Above 326° the groundmass darkens slightly, the configuration of the fossils is sharper, the matter in the cell interiors becoming granular in structure, and so changed as to give the colonies a pitted aspect. Above this temperature all the components grow darker under greater heat, until at 410° the colonies are hardly distinguishable from vestiges of other débris in the groundmass, and the whole darkened section assumes a warm wine-red color.

[1] B. Renault, *Sur Quelques Microorganismes des Combustibles Fossiles*, St. Etienne, 1900.

[2] E. C. Jeffrey, "The Nature of Some Supposed Algal Coals," *Amer. Acad. Arts and Sci. Proc.*, Vol. 46 (1910), pp. 273–90, pls. 1–5.

[3] Reinhardt Thiessen, "Origin of the Boghead Coals," *U.S. Geol. Survey Prof. Paper 132*, Washington, 1925, pp. 121–37.

At 457° the colonies swell, the cell contents protrude, the fossil masses brighten and suddenly form a violently boiling yellow-red mass. This action is immediately followed by volatilization, with condensation of a part of the hydrocarbons in rather viscous turbulent brown streams or patches. On further advance of temperature these appear to dry up (volatilized), and the shrinking residues darken and shrivel to a thin carbon tracery, in which the pattern of the cross-section of the cells forming the colony is more or less distinctly visible. Apparently the residual carbon centers largely along the lines of the original cell laminae, most of the fatty thickening, which forms the greater part of the mass of the alga, having volatilized.

The carbonization of the "ulmic" groundmass proceeds more slowly, though with evident variations in the rate of change of volume through different temperature zones, but there is no visible optical change even at temperatures up to 700° C.

The temperatures at which some of the changes, noted above, take place vary apparently with the rate of heating. For example, with very rapid heating the section does not darken perceptibly until the temperatures approach the melting and volatilization points of the fatty matter of the colonies; but it is important to note that in all tests the rapid reaction attending volatilization occurs at a fixed temperature. The heating periods have ranged from 39 minutes to 2 hours and 14 minutes.

It is interesting to note that with the slightest access of oxygen the phenomena differ, especially at certain temperatures. Thus both the algal colonies and the groundmass darken at lower temperatures, the increasing opacity being evident at 250° C., and progressing still more rapidly at 425° when rapid reduction in volume is observed, with the opening of large shrinkage cracks at about 450°. At 480° the section is absolutely opaque, while at 580° the colonies become visible again, being wine-red and clearly delineated in the almost black groundmass and other matter. At about 605° the colonies gradually lose their reddish color, turn paler and fade, leaving empty burned-out holes. At 634°, or thereabout, new shrinkage cracks appear and the black carbonaceous residue begins to burn slowly.

Kiskiminetas cannel.—The cannel occurring in the Freeport group at Kiskiminetas Junction, Pennsylvania, has been described and microscopically illustrated by Thiessen[1] and Fettke.[2] The scarcity of large spore exines, which makes this rock less advantageous for microthermal observation, is to a degree compensated by the unusually large number of colonies of fatty micro-algae which, as pointed out by Thiessen, are evidently similar in structure and nature to *Reinschia* and the *Pila* of the Mississippian and Permian bogheads.

In this cannel measurable swelling takes place between 117° and 170° C., a relatively low temperature, while the section presently becomes more translucent. This is very likely due to melting of some of the matters, presumably in the groundmass. Cuticles come into sharp definition and remain in brilliant image until a temperature of about 230° is reached, while also swelling of the colonies is observed, with a degree of obliteration of the cell cavities, presumably as the result of melting of the cell wall thickening. At a slightly higher temperature (234°) melting and some flowage of the algal substance is noted, while the colonies are turning to an orange-yellow, with vagueness of marginal definition and deepening of the interior pits.

Fading of many of the spore exines may be observed, the cuticles lose distinctness around 285°, and a little later, at 298°, the algal colonies are deeply pitted and have assumed a spongy aspect, being evidently reduced in volume. Some of the spore exines vanish near 310°, and at 330° the cuticles have almost disappeared, while the red hues in the section are turning to brown. The section darkens rather rapidly at 340°, probably with loss of volatile matter from the exines, and at 351° shrinkage of the groundmass is evident. At 379° the algal colonies seem to be fused with flowage over the internal pits, the groundmass is nearly opaque, all spores having nearly vanished, and traces of cuticles are barely recognizable.

Further marked shrinkage (partial volatilization) of the ground-

[1] *Op. cit.*

[2] C. R. Fettke, "Cannel Coal and Carbonaceous Shale Deposits of Pennsylvania," *Amer. Inst. of Min. and Met. Eng.*, Vol. 69 (1923), p. 1170. "Oil Resources in Coals and Carbonaceous Shales of Pennsylvania," *Pennsylvania Geol. Survey Bull. M-2.*

mass is observed at 413°, and at 445° the algal colonies have turned to a russet red, are losing definition, and doubtless have lost some of the volatile matter. The whole section is almost opaque at 471°, beyond which carbonization of the residues and groundmass appears to proceed slowly, the section being black and entirely opaque beyond 606°; however, apparent increases in the rate of shinkage, with enlargement of cracks, at 625° and at 645°, are interpreted as indicating probable changes with more rapid loss of volatile matter around these points. From 697° to 792° the residue remains opaque, unchanging, and resembles glistening black coke.

Devonian bituminous shale.—To illustrate a very different type of carbonaceous shale a sample collected by Professor L. G. Westgate from the lower part of the Huron shale near Delaware, Ohio, may be taken. The sample is representative of the rather richly carbonaceous phase of the Huron and contains large numbers of *Sporangites huronensis*, which may easily be watched in the microfurnace, where they appear pale yellow or brassy. The following observations of the behavior of this rock are incomplete, but certain rather definite changes in the "ulmic" groundmass and the Sporangites exines are noteworthy.

The apparently homogeneous structure of the Sporangites wall exhibits a granular structure, possibly the cell mesh, near 140°. At about 180° the whole rock section becomes more luminous and slightly swollen, probably the result of some fusion in the groundmass, which at 250° changes from a gray-brown to a warm brown and becomes more granulated in aspect.

The Sporangites walls break up into lumps at a temperature near 270°, their surfaces becoming deeply pitted, as though by loss of glandular or other substance, and a little later, at 290°, shriveling to some extent has taken place in these exines, which between 305° and 350° turn much darker.

At 356° the groundmass also begins to grow darker, and near 375° some of the Sporangites have deepened to an amber-yellow while the groundmass has been swelling. It remains to be seen whether the change of color just noted in the Sporangites may be due to condensation of vapors from the groundmass. The Sporangites have darkened and become nearly brown at 455°; and at 460°,

5° higher, melting and volatilization of the Sporangites suddenly takes place. The brownish residues of the Sporangites walls have faded by the time the temperature reaches 520°. At 570° cracks appear in the groundmass and further acceleration of shrinkage is indicated around 598°. Enlargement of the shrinkage cracks is observed in the vicinity of 700°, and at about 727° light spots appear, marking cavities previously occupied by the Sporangites, while a little later, at 761°, the outlines of the tenuous Sporangites residues are more clearly defined. No further changes were observed up to 850°, when the heat test was discontinued.

This test indicates distinct differences in composition between the Sporangites and the groundmass, with consequent differences in the temperatures of volatilization or heat decomposition. It is interesting to note the relatively large percentage of volatile matter in the Sporangites as inferred from the slight amount of the residue left after carbonization in the inert atmosphere.

Oil shale from Parachute Creek, Colorado.—Oil shale from the site of the new government plant on Parachute Creek, Colorado, was submitted through the courtesy of Mr. M. J. Gavin, of the U. S. Bureau of Mines. The organic material in this shale consists mainly of the almost structureless light-yellow to brown "ulmic" groundmass, which envelops brown cuticles, pale amber-colored spores, some resins, occasional chitinous skins of insect larvae, and rarely, algal groups.

As the section is slowly heated, the groundmass becomes darkened at 223° and the spores change from amber-yellow to reddish-brown, possibly as the result of flooding by the groundmass. A little later, at 230°, the groundmass assumes a granular aspect, after which little change is noted until the temperature reaches 272°, when the warm tone changes to a darker brown.

At about 380° the groundmass, which has been darkening, becomes quite dark, the cuticles and spores are fading and the colonies have lost their brilliancy, being nearly brown, and appearing somewhat in relief, while, at the same time, they are broken into spongy lumps. At 506°, however, most of the colonies are fading and the few that remain visible are brown. At 580° all the cuticles and spores have faded and carbonization is apparently complete.

For thirty minutes thereafter the section was kept at this temperature without definite visible change.

When, however, heating was continued and the temperature was brought up to 760°, almost instantaneous combustion took place and the outlines of the spores and colonies became relatively distinct on account of the burning out of their residues.

In this, as in many other cases, oxidation or combustion appears to be selective, according to the composition of the particular fossil constituent or residue.

It will be remembered that the furnace is air-tight and that in the flow of purified helium no oxygen was available for the combustion of the organic matter in this section from the Green River shale. It is, therefore, naturally inferred that this sudden reaction is due to the reduction or decomposition of inorganic matter in the rock, and the consequent oxidation of organic matter in the spore, cuticle, and algal residues.

In another test which was carried out with a rapid rate of heating so that a temperature of 400° was reached within a few minutes, melting and partial volatilization of some spores was noted when the temperature reached 475°; but when another section was heated at a slow rate, the evidence of volatilization of spores was very obscure. This may indicate a narrow volatilization zone.

It is of interest to note that in a test in which unpurified helium was used, without evacuation of the furnace, visible combustion set in as the temperature was slowly raised slightly above 520°.

The interpretation of these, the most obviously visible changes in the rock, must for the most part await the retort and chemical tests which should follow the microfurnace observations as the second step in this study.

PRELIMINARY CONCLUSIONS

The work has not yet gone far enough fully to determine either the applications and values or the limitations in the use of the microfurnace in the study of carbonaceous deposits; in the investigation of their composition and changes; and in the solution of the problems, both of the sources of the chemical components of the distillates and, by inference, of the origin of the natural petroleums. In

passing, however, it is to be noted that while in some cases the process promises to exceed expectations, it is at the same time evident that in other cases it will leave much to be desired.

The observations are liable to error, due (1) to melting and flooding of the "ulmic" groundmass, which may mask changes in the spores, while, on the other hand, the overflowing of the "ulmic" matter may cause changes of color or aspect without actual physical or chemical changes in the organic débris itself; (2) to fluctuation in the intensity of the illumination, for it is very difficult to maintain that degree of uniformity of illumination by an arc light that is necessary adequately to project the images of thin sections of these dark hydrocarbon rocks; and (3) to change of focus due to warping or change in volume of the section.

The following conclusions are indicated.

1. The different organic fossil constituents, such as spore exines of various kinds, cuticular fragments, algal débris or colonies, and waxy and resinous bodies, in a given section of the oil shale or other rock have different temperature zones of change, most of the constituents exhibiting several noticeable changes of color or volume as the temperature rises. These temperature distinctions can be due only to differences in the present chemical composition of the fossil constituents. Though most or all of the physical organic material is altered more or less since deposition, distinctions arising from original differences in chemical constitution are not yet wholly obliterated.

2. In some of the plant structures, like those of the fatty algae, which are more readily observable, the different parts, such as the cell laminae, the fatty thickening of the walls, and the cell contents, react at different temperatures, due to differences in chemical composition.

3. In certain fossil constituents the main volatilization occurs instantaneously at definite temperatures. In some other materials the changes may be masked and are not so clearly definable. Some changes are gradual and take place through limited zones of temperature.

4. The "ulmic" or "humic" groundmass, or "biochemical concentrate," regarded by many geologists as the source of the oils,

seems in most cases to pass through two or more phases or zones of notable change with reduction in volume at different temperatures.

5. The temperatures, or temperature zones, of change in the groundmass seem to vary in consequence of (*a*) the type (presumably original composition) of the concentrate, and (*b*) its stage of natural carbonization. The composition of the groundmass, including attrital matter of varying origin, is complex. Apparently the carbonaceous sediments represent chemical as well as physical agglomerates in colloidal state. In its later stages of carbonization the "ulmic" groundmass material appears to be comparable to coal in the later stages of coking, in which very heavy high-boiling-point hydrocarbons containing very small proportions of hydrogen are driven off in zones of higher temperature.

6. In some organic rocks the critical temperatures or zones of change are rather higher when the section is heated rapidly than with slower heating; but where melting and volatilization take place at a definite temperature, time and rate of heating seem to have little or no effect.

7. The effects of oxidation are readily detected, and oxidation even to a slight extent reduces the yield of oily and volatile substances. It is evident that in any experiments aimed at the discovery of normal underground reactions, oxygen from sources outside of the rock should be totally excluded.

8. In the final stage, the thin section presents a black carbon residue, the thickness and pattern of which naturally differ according to the structure and the volatile matter contained in the different fossil constituents or the groundmass.

THE GEOLOGIC STRUCTURE OF A PORTION OF THE GLASS MOUNTAINS OF WEST TEXAS

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ABSTRACT

In the Glass Mountains of west Texas a thick section of marine Permian rocks is exposed. It rests unconformably upon strongly folded Pennsylvanian and early Paleozoic rocks and is unconformably overlaid by Comanchean beds. The regional structure is a northwest dip of from 5° to 15°. Minor structures consist of some northwest trending faults of short length, but locally with considerable throw. It is concluded that these structures are of post-Comanchean age and that a little more than half the deformation in the mountains took place at that time. The pre-Comanchean folding consists of a northwest-dipping monocline upon which are minor arches whose relationship to the later anticlines is of an erratic nature.

This paper, based on two and one-half months' study in the western portion of the Glass Mountains, is presented in the hope that it may prove to be of assistance to geologists working in the oil-producing areas farther to the northeast where only Comanchean strata are exposed at the surface.

STRATIGRAPHY

The detailed stratigraphic studies made by the writer generally confirm the reconnaissances of Udden and others[1] in the same area, so that only brief mention of the formations need be made here.

Pre-Permian rocks.—These consist of the Maravillas chert and Caballos novaculite, of Ordovician and possibly Devonian age, respectively, and of several thick Pennsylvanian formations. They are complexly folded, and since they do not directly concern the present problem they will not be described.

Permian rocks.—The Permian rocks rest with profound angular unconformity upon the earlier beds and are in turn similarly overlaid by the Comanchean. The formations are all of marine origin and are characterized by great thicknesses and by notable variation in thickness and lithology of individual layers within short distances.

[1] J. A. Udden, "Notes on the Geology of the Glass Mountains," *Bureau of Economic Geology, University of Texas, Bull. 1753.*

The Leonard formation at the base of the section varies from 1,600 to 2,100 feet in thickness and has at its base an unconformity, the earlier Permian, Hess, and Wolfcamp formations having been removed prior to its deposition from the area under consideration. It consequently rests upon strongly folded Pennsylvanian rocks. The formation is characterized throughout by conglomeratic material, ranging from angular bowlders at the base to small rounded pebbles at the top. It consists in its lower part largely of limestones, in the middle of thin layers of limestone interbedded with shales and siltstones, and in the upper of shales with some sandy layers.

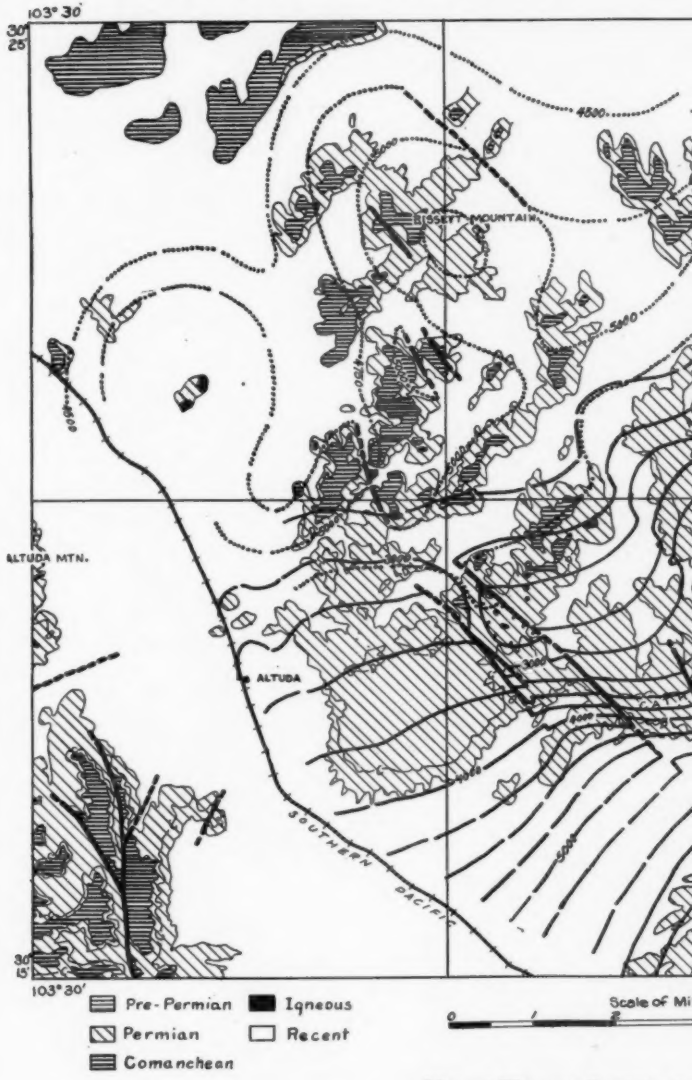
The Word formation has, at its base, a persistent layer of bituminous limestone, above which are fine-grained sandstones and sandy shales, with some more calcareous beds. Its thickness varies from 800 to over 1,500 feet.

The Vidrio formation consists of massive homogeneous dolomite with indistinct bedding planes. At least 2,000 feet of this material is exposed in the area, but neither the Gilliam nor the Tessey formation, described by Udden as overlying the Vidrio, was recognized in the area studied.

Comanchean rocks.—The Comanchean consists of thin layers of marly limestone having several well-marked fossil zones and, locally, thin conglomerate beds at its base. The maximum thickness remaining in the area is about 300 feet. These beds rest with angular unconformity upon the Permian, lying on the highest beds of the Vidrio formation in the north, and upon the top of the Word formation in the southwest.

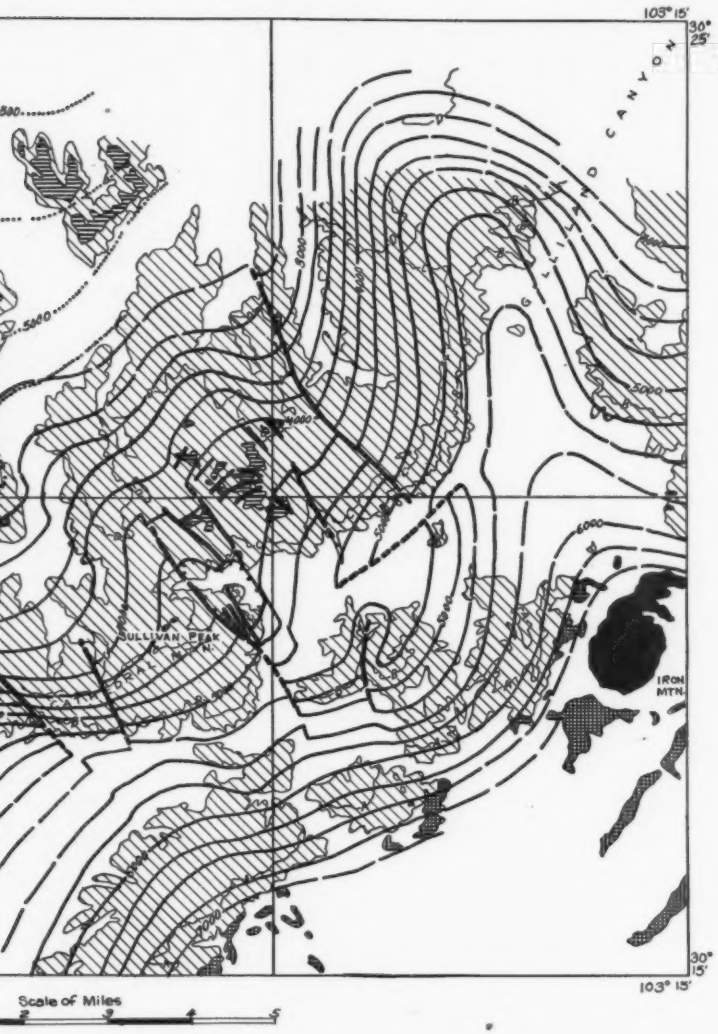
MAJOR STRUCTURES

Glass Mountains.—The most prominent structural feature, shared by both Permian and Comanchean, is a general inclination to the northwest (Plate 28). In the Permian this locally exceeds 20°, but is ordinarily much less, in some places being less than 8°; in the Comanchean it is not known to exceed 5°. There appears to be a general decrease in dip toward the northwest, so that both Comanchean and Permian are less tilted on the flanks of the mountains. Superimposed on this regional structure are minor ones which consist of various folds and faults.



MAP OF WESTERN PORTION OF

Contour interval, 250 feet; solid lines contoured on base of Word formation, Permian are obtained from four key beds: *A*, *B*, *C*, and *D*. *A*, bed in lower pa formation; *D*, a bed from 500 to 700 feet above the base of the Vidrio formation



PORTION OF THE GLASS MOUNTAINS

d formation, dotted lines on a Comanchean horizon. The data for the contours on the
in lower part of Leonard formation; *B*, base of Word formation; *C*, base of Vidrio
io formation.

Del Norte Mountains.—Southwest of the Glass Mountains is a sharp northwest-trending anticline whose axis lies near the crest of the Del Norte Mountains. This is accompanied by auxillary parallel folds on the flanks, and by faults, and zones of crumpling in which beds locally attain dips of 60°. Northwest of the Del Norte Mountains is the uplift of Altuda Mountain, in which horizons as low as the Leonard formation have been brought to the surface by an igneous intrusion. As this area was not studied in detail, its exact relationships are unknown, but apparently it is separated from the Del Norte folds on the south by a fault of over a thousand feet throw, while to the northwest successively higher and higher beds dip away from the center of the uplift.

MINOR STRUCTURES

Faults.—The Glass Mountains are cut by a series of faults which involve both Permian and Comanchean rocks. These are particularly well developed in the high mountains about three or four miles on either side of Sullivan Peak. A few are seen in the northwest foothills, particularly near Bissett Mountain; southeastward they appear to die out and none are seen in the escarpment of the lower part of the Leonard formation.

Most of the faults have a northwesterly trend, though a few lie at right angles to this. The most notable of the latter is found at the foot of the main escarpment of the mountains northwest of Iron Mountain, which results in a double outcrop of the base of the Word formation and an apparent thickening of it in some of the sections. Many small faults of similar trend were observed in the Comanchean on the mountain summits about two miles north of Sullivan Peak.

A large fault which cuts the main escarpment two miles northwest of Sullivan Peak has an inclination from the vertical of more than 30°, and is a reverse fault. At some other localities where the fault planes were observed they stood nearly vertical, so that whether they are of normal or reverse type is uncertain, though it is probable that they also are reverse faults.

Several of the faults have a throw of more than 700 feet but none has been traced for more than four miles. Not uncommonly they are lost in the homogeneous dolomite of the Vidrio formation or

pass under alluvial deposits, but where traceable they are seen to die out rapidly.

There is no regular placing of their upthrown and downthrown sides. In several places, however, two parallel faults form grabens, the two most notable of these being on the eastern spurs of Sullivan Peak and three miles west of the Peak. In both of these the middle portion of the graben is a deep structural depression from which the strata rise both to the northwest and southeast with a corresponding decrease in the throw of the limiting faults. In the graben east of Sullivan Peak the strata are broken by minor parallel faults into wedge-shaped masses of varying dip and displacement.

The eastern border of the Del Norte Mountains is marked by faults similar to those in the Glass Mountains. The fault at the southern border of the Altuda Mountain uplift has already been mentioned.

Folds.—The most salient fold in that part of the Glass Mountains studied is a plunging anticline which extends northward from Iron Mountain with a trend of approximately N. 20° W. For about five miles its axis lies in Gilliland Canyon, beyond which it appears to pass directly across the mountains (Plate 28). A strong fold seen in the Comanchean about five miles southwest of Hovey may lie on its northwest extension. The dip on the west flank of this fold is about 15° toward the west, but on the east flank the inclination is toward the north and northeast at a slighter angle.

A less well-defined anticline appears to originate in the neighborhood of Sullivan Peak and to trend from there in a northwesterly direction. Near its point of beginning it is merely a buckle in the regional dip, and in places it is bounded by faults, but at Bissett Mountain, six miles to the northwest, it has developed into a broad arch with a local doming on its crest. There is some evidence that this doming marks the intersection with a northeast fold coming out from the uplift of Altuda Mountain. About halfway between Bissett Mountain and Altuda Mountain an isolated hill on Young's ranch has several exposures of igneous rock intruded into a pink quartzite correlated with that found elsewhere near the middle of the Word formation. The relationships of this outcrop are uncertain, but the

rock is high above its normal position, and, as stated, it lies on a trend between the uplifts of Bissett Mountain and Altuda Mountain.

AGE OF THE DEFORMATION

The writer believes that all the structural features described above are of post-Comanchean age. Nearly all the faults and folds described involve the Comanchean, or are related to igneous intrusions of post-Comanchean age. Some of the folding may be of Larimide age, but on Mount Ord, on the west flank of the Del Norte Mountains, Tertiary[1] lavas are seen to be tilted equally with the Comanchean in the folds of those mountains. Other than this no definite evidence was obtained as to the date of the folding. An erosion surface noted at several places on the Glass Mountains is believed, from its relationships, to have been formed before the deposition of the Comanchean. From their form it is believed that many of the high summits of the mountains are a part of this old surface from which all trace of the soft overlying formations has been removed.

As already noted, an angular unconformity separates the Comanchean from the Permian. A study of elevations and profiles indicates that less than half of the present inclination was produced during the pre-Comanchean diastrophism.

PRE-COMANCHEAN STRUCTURES IN THE PERMIAN

A study of pre-Comanchean structures is rendered peculiarly difficult by several factors. All comparisons between Permian and Comanchean folds must, with few exceptions, be made in the massive homogeneous Vidio formation in which dips are difficult to obtain and horizons hard to trace. The abundance and complexity of post-Comanchean structures obscure all earlier folds. Finally, there is a possibility that the Comanchean was deposited on so rugged a surface that the thicknesses of strata beneath are unreliable for studies in structure.

The writer is inclined to minimize the latter difficulty, and he believes that the pre-Comanchean erosion surface was much more

[1] C. L. Baker, "Geologic Exploration of the Southeastern Front Range of Trans-Pecos Texas," *Bureau of Economic Geology, University of Texas, Bull. 1753*, pp. 123–24.

level than has been supposed.[1] Much of the apparent irregularity in the ancient surface has been caused by post-Comanchean faulting,

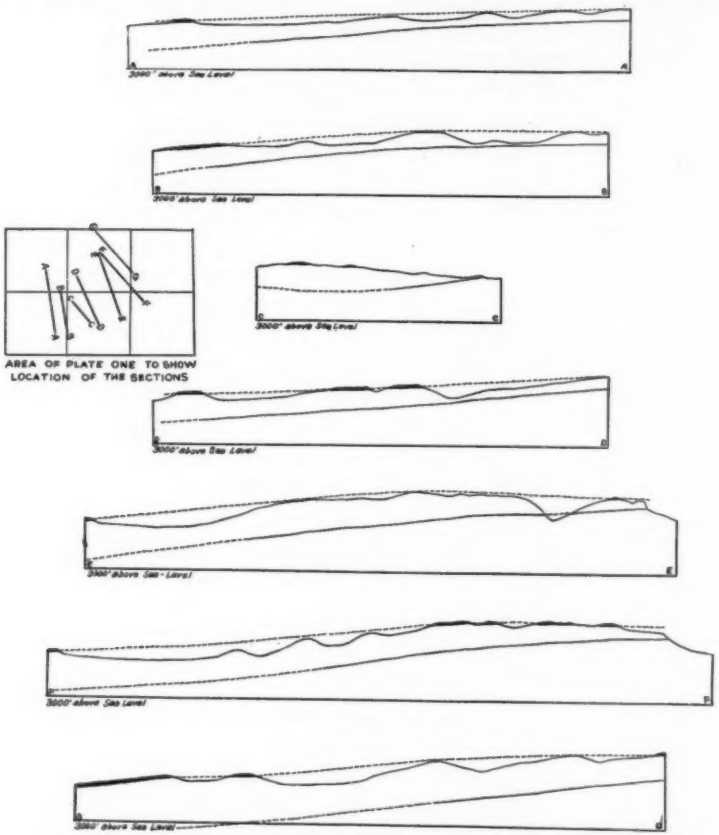


FIG. 1.—Cross-sections across Glass Mountains showing relation between the Comanchean and the base of the Vidrio formation. Comanchean rocks are shown in black and the restored base of the Comanchean by dotted lines.

and the Comanchean horizons, so far as worked out, appear to be uniform and continuous (Fig. 1).

[1] J. A. Udden, "Notes on the Geology of the Glass Mountains," *Bureau of Economic Geology, University of Texas, Bull. 1573*, p. 54.

After taking into account these difficulties it is found that in the pre-Comanchean folding of the Permian there was a fairly regular dip to the north-northwest, apparently less broken by minor structures than is the present regional dip. It seems clear from the data on hand that neither the faulting nor the prominent anticline in

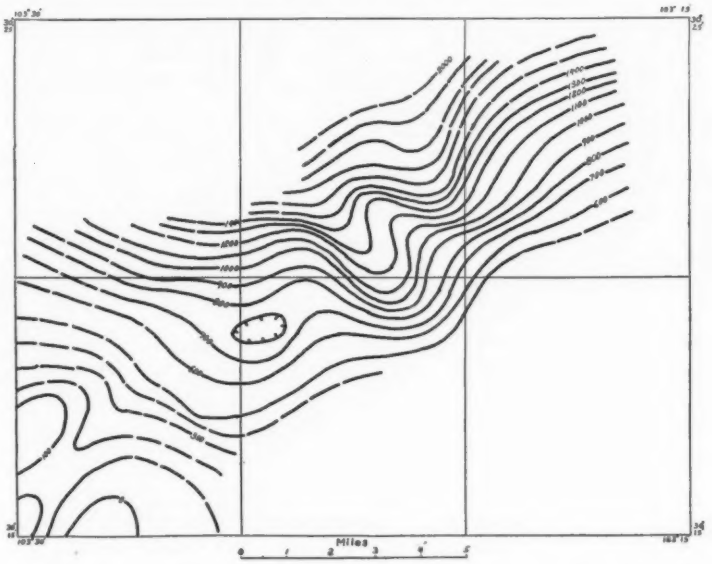


FIG. 2.—Approximate position of pre-Comanchean structures in the Permian. Contour lines represent thicknesses between a Comanchean horizon and the base Vidrio formation. Contour interval, 100 feet.

Gilliland Canyon had any counterpart in the earlier folding. Irregularities, however, are discernible in the thicknesses between certain Comanchean and Permian horizons which indicate that minor structures did exist. These are best seen in the Del Norte Mountains where the base of the Comanchean and the base of the Vidrio are close together. It appears that there were several low arches here, with synclines between, having a northeast trend, which have no relation whatever to the present fold of the Del Norte Mountains.

The most notable feature of this folding in the Glass Mountains is a considerable depression in the area northwest of Sullivan Peak (Fig. 2). This apparently has much the same position as the anticline of post-Comanchean age already described.

Thus, in this limited area, there is a suggestion that the relationship between post-Comanchean and pre-Comanchean structures is most erratic, for one anticline of the later folding appears to have no counterpart in the earlier, in another the folds of one are at right angles to the other, while a third seems to be represented not by an anticline but by a syncline.

WILCOX SAND PRODUCTION, TONKAWA FIELD, OKLAHOMA

GLENN C. CLARK
Ponca City, Oklahoma

INTRODUCTION

Development of the deep sand production at Tonkawa began with the completion of Slick No. 1A, SW. corner Sec. 35 T.25 N., R.1 W., Kay County, Oklahoma (Plates 29 and 30), early in April, 1924.

Well-log correlation with deep tests in this general area placed the producing horizon in basal Cherokee or near the top of the "Mississippi lime." Samples of the sand, however, showed typical Wilcox characteristics, which fact indicated an exceptional structural and erosional condition. Meager evidence had led to the conclusion that a similar condition, with "Mississippi lime" absent and Wilcox sand in contact with basal Pennsylvanian shales, exists in prominent structural fields such as Eldorado, Kansas; Cushing and Blackwell, Oklahoma. An opportunity was offered at Tonkawa to secure the necessary data to support this theory (Figs. 2, 3, 4).

STRATIGRAPHY

Production at Tonkawa above the Wilcox sand is from five sand horizons included in a zone 750 feet in thickness, the top of which is 900 feet below the Pennsylvanian-Permian contact and the base about 1,450 feet above the base of the Pennsylvanian. This zone of producing sands is correlated with that part of the Osage County surface section between the Big Heart and Elgin sandstones. An average thickness of Permian over the higher part of the structure is 950 feet.

The Tonkawa sand, found at a depth of 2,450 or 2,500 feet, is the deepest producing horizon of the Pennsylvanian sands. The only prominent sand between the Tonkawa and Wilcox is the 3,100-

foot sand, which may be correlated in a general way with the Layton sand of the Cushing district. In drilling the deep wells the common practice is to cement the $8\frac{1}{4}$-inch casing below this water sand and complete the wells with standard tools.

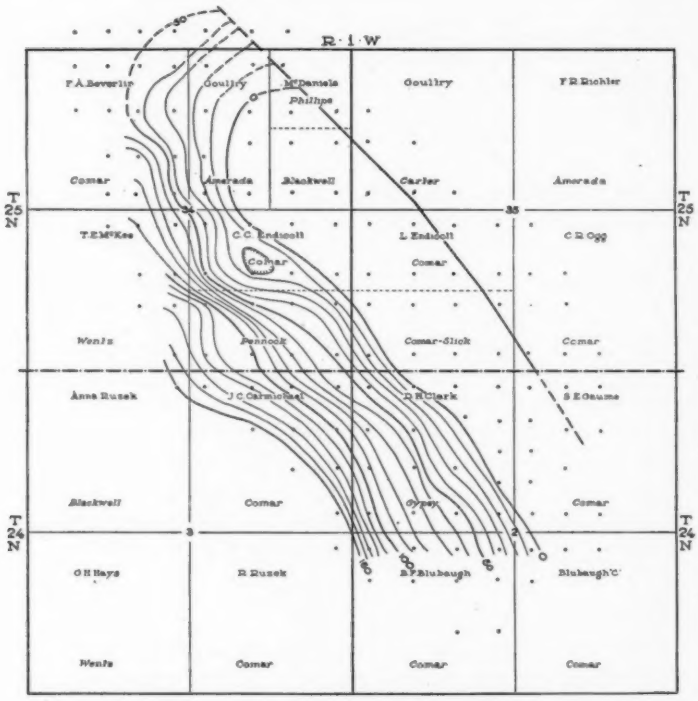
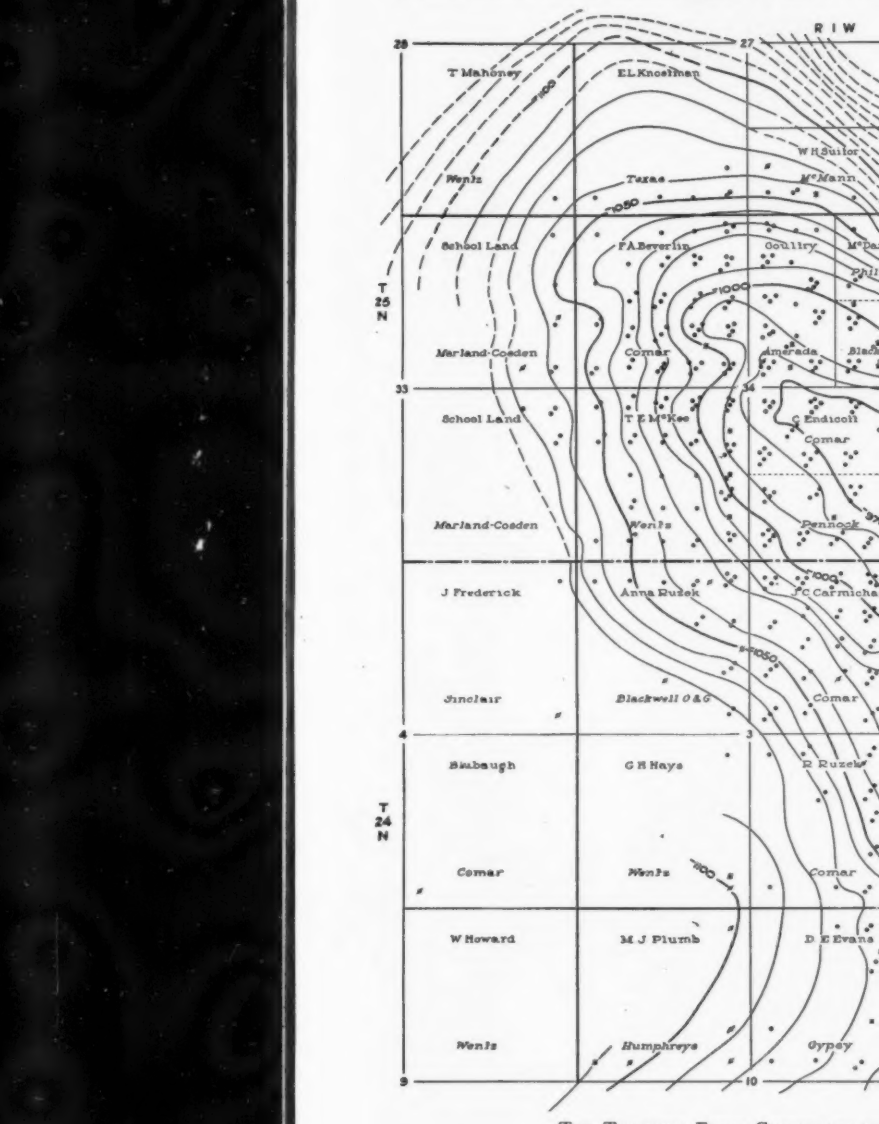


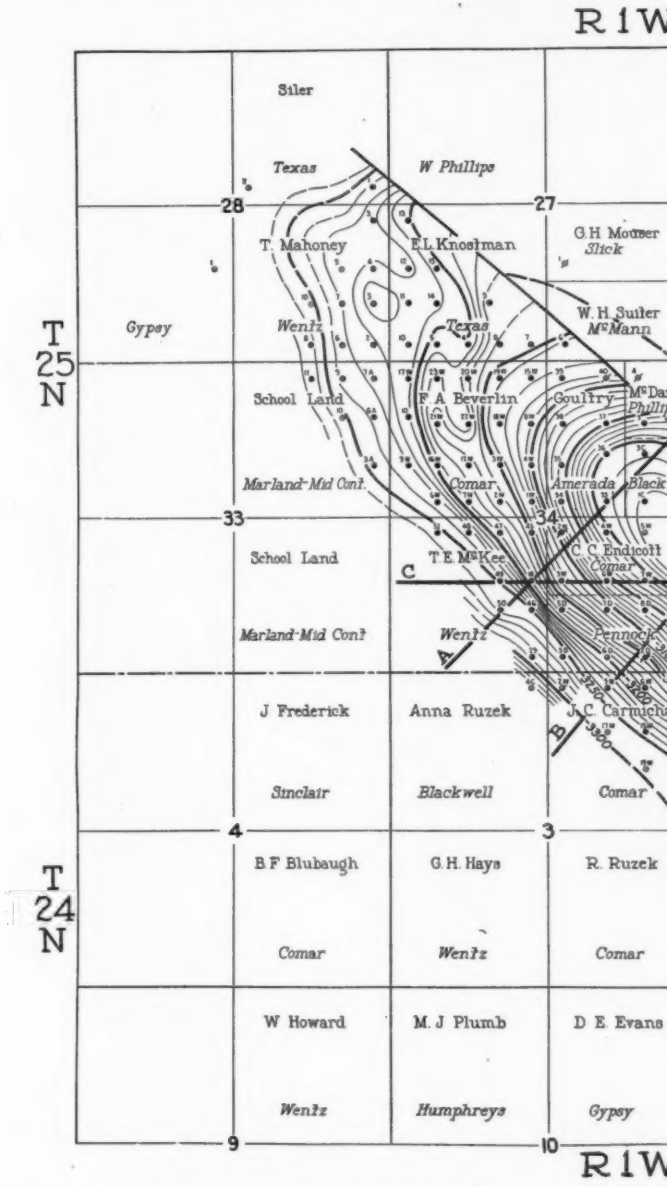
FIG. 1.—Tonkawa field. Isopach map of the "Mississippi lime"

The Oswego–Big Lime series is about 200 feet thick and is made up of prominent limestone beds. The individual members, however, are not easily correlated from well to well. The Cherokee shale is approximately 265 feet thick, with a persistent red shale bed about 215 feet below the base of the Oswego–Big Lime series. This red shale lies some 50 feet above the unconformity between basal Cherokee shale and the older formations.

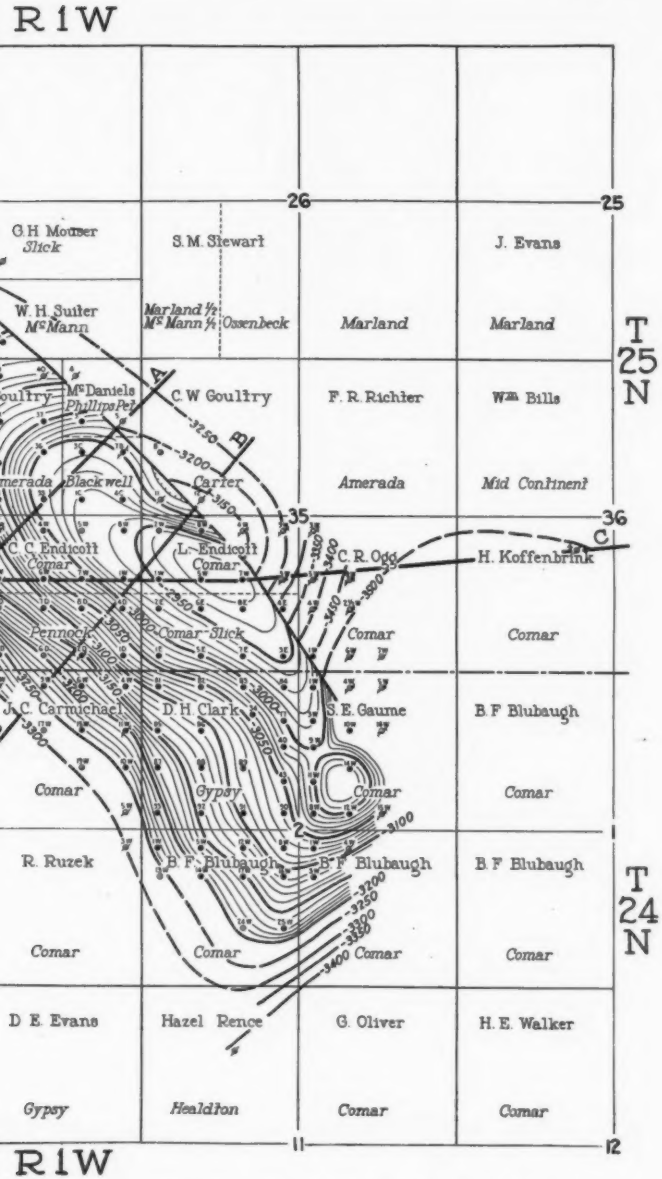


THE TONKAWA FIELD CONTOURED ON

ONTOURED ON THE LOWER HOOVER SAND



THE TONKAWA FIELD, WILCOX SAND WELLS AS OF JUNE 4, 1



OF JUNE 4, 1926. CONTOURED ON THE TOP OF THE "WHITE LIME"

The "Mississippi lime" on top of the structure is absent and increases in thickness toward the sides up to 150 feet in wells along the western edge of the field (Fig. 1). The normal thickness in this general area to the east, where not influenced by folding, is about 300 feet. The upper 50 to 75 feet are light-colored chert, commonly called the "chat"-producing horizon; the remainder is dark gray to dark limestone.

Underlying the "Mississippi lime" are about 30 feet of black shale, generally recognized as Chattanooga. This shale does not cave like the dark shale found just above the "Mississippi lime."

Overlying the Wilcox sand and just below the Chattanooga shale is a light-colored, crystalline limestone about 30 feet in thickness. This limestone has the same characteristics as its equivalent in the Okmulgee district, the "white lime," and is so called at Tonkawa. It is correlated with Upper Viola of the Arbuckle section. The lower part of this formation produces some oil. In some cases the upper part carries water. Operators generally set $6\frac{5}{8}$-inch casing near the middle of this lime.

The Wilcox sand varies from the tight quartzitic type to the loosely cemented, clear, well-rounded sand, characteristic of Wilcox over Kansas and Oklahoma. As found in the few wells that have been drilled into the "siliceous lime" below, the Wilcox has a thickness of 280 feet. No attempt is made to subdivide the Wilcox except in a general way, based partly on producing zones. Due to the difficulty in securing samples from flowing wells, little is known as to whether correlations may be made from well to well on lithologic characteristics of horizons within the upper, productive part of the Wilcox. As in many other fields, the green shale formation divides the Upper and Lower Wilcox but, in the writer's opinion, this is the only means of subdivision at the present time.

The first pay zone includes about 40 feet of sand immediately below the "white lime" and the second includes that between 60 and 120 feet in the sand. There seems to be a non-productive zone of 20 to 30 feet in thickness between these two pay horizons. The upper 100 to 120 feet of Wilcox sand have no shale breaks of consequence. Immediately below this is found a dark shale bed about 30 feet thick. In general appearance this shale is not unlike the Chat-

tanooga, but upon careful examination shows a certain resemblance to the green shale associated with the Wilcox sand. Included between the base of this shale and the top of the "siliceous lime" are interbedded sand and dark shale beds. No increase in production has been found in this lower phase of the Wilcox.

The uncommon amount of shale associated with the Wilcox sand probably is an important factor in the high oil recovery at Tonkawa. The fact that this shale is much darker in color than the ordinary green shale of this horizon is also significant in this respect.

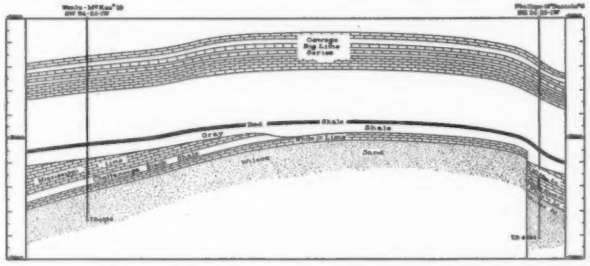


FIG. 2.—Cross-section of Tonkawa field along line *A–A* of Plate 30. Horizontal scale one-half vertical scale.

The "siliceous lime" has proved productive in two wells, Gaume 14W and C. C. Endicott 8W, but the results have indicated that large production is not to be expected from this horizon. Experience in other fields has been that where either the Wilcox sand or the siliceous lime is highly productive little may be expected from the other.

STRUCTURE

The Tonkawa structure lies between the alignment of granite-ridge structures including Eldorado, Oxford, Blackwell, Retta, Thomas, and Garber and the less prominent line of folding through the Beaumont, Dexter, Newkirk, and Ponca fields. Though apparently not connected with either of these, it has a close resemblance to the typical granite-ridge structures.

The major part of the folding connected with the Tonkawa structure must have taken place at the close of Mississippian or during early Pennsylvanian time. The presence, in the immediately

surrounding area, of "Mississippi lime" in approximately full thickness would indicate that conditions were stable during the time of its deposition. This folding and the faulting along the northeastern edge of the field were probably a part of the same general movement. Subsequent erosion removed the "Mississippi lime" from the higher part of the fold and the white lime from the extreme peak. After this period of erosion, followed by submergence, Pennsylvanian sediments were deposited over the truncated edges of the pre-Pennsylvanian formations.

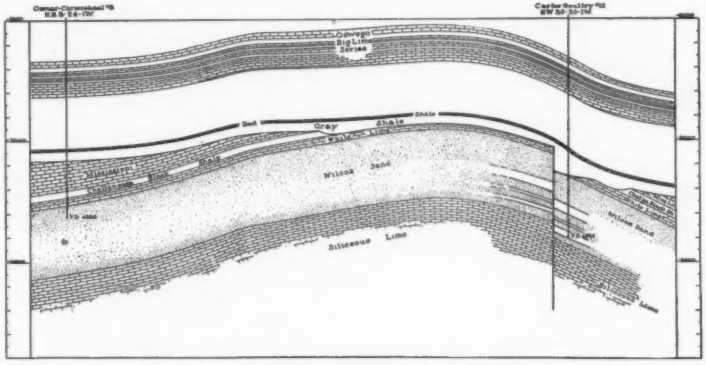


FIG. 3.—Cross-section of Tonkawa field along line *B–B* of Plate 30. Horizontal scale, one-half vertical scale.

The topography of this erosion surface was reflected in diminishing degree as deposition continued. A structure map contoured on any Pennsylvanian horizon would represent, in a general way, this topography. A comparison of the structure map contoured on the lower Hoover sand (Plate 29) with that contoured on the white lime (Plate 30) is, excepting in degree of dip, essentially a comparison of the pre-Pennsylvanian topographic map with the structure map of the pre-Pennsylvanian formations. Attention is called to the difference in size and apparent difference in lateral position of the area inclosed within the highest contour in the comparison of the two structure maps. As seen in the cross-sections (Figs. 2, 3, and 4), the wedge-shaped remnant of "Mississippi lime" along the western

flank of the fold has been largely responsible for these differences. Such influence on the east side is removed by the fault of over 300 feet throw. It seems that the white lime "high" lies east of the lower Hoover "high," thus indicating a shifting eastward with depth. It will be noted, however, that the east dip of each begins at practically the same point, and the difference in appearance is due to width and degree of dip.

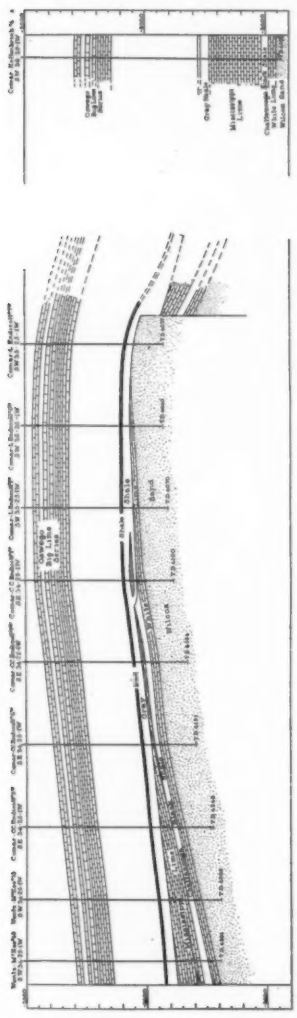


FIG. 4.—Cross-section of Tonkawa field along line *C–C* of Plate 30. Horizontal scale one-half vertical scale

The dip of Pennsylvanian and Permian formations along the southeast side of the field is more pronounced than that along the northeast side. This steep southeast dip into a prominent syncline is continuous along the east side of the pool in Secs. 29 and 30, T. 24 N., R. 1 W., and the old Billings pool in T. 23 N., R. 2 W. These three pools are located on the same general line of folding, but extensions north and south are not evident. Unfortunately, drilling has not given sufficient information on the east dip to disclose whether or not this is due to faulting.

The limit of Wilcox sand production on the southwest side of the field is defined by a contour approximately 300 feet lower than the top of the structure. The position of this contour is followed by contours on shallow sands from 50 to 80 feet down-dip. The northwest extension is the

only part of the field in which the limit of Wilcox production equaled or exceeded that of the shallow sands.

PRODUCTION

Total Wilcox sand production to January 1, 1926, was 28,305,000 barrels, an average of 21,443 barrels per acre over the 1,320 acres that produced oil from this horizon. Similar production from shallow sands to the same date was 49,258,000 barrels, an average of 18,729 barrels over 2,630 acres.

Up to this same date the Slick-Endicott 80 acres, the S. ½ of the SW. ¼ of Sec. 35, T.25 N., R.1 W., had produced 46,450 barrels per acre from shallow sands and 26,875 per acre from the Wilcox sand, a total of 73,325 barrels per acre. There is a reasonable possibility that this tract will have an ultimate yield exceeding 100,000 barrels per acre. The Beverlin 160 acres, NW. ¼, Sec. 34,T. 25 N., R.1 W., had produced an average of 30,762 barrels per acre; and the C. C. Endicott 80 acres, N. ½, SE.¼, Sec. 34, T.25 N., R.1 W., 34,037 barrels from the Wilcox sand. The production record of McKee No. 45, Wentz Oil Corporation, in the NE. corner of the SW. ¼, Sec. 34, T.25 N., R.1 W., will doubtless equal or surpass that of any other well in Oklahoma or Kansas. It had an initial production of about 10,000 barrels, and up to January 1, 1926, had produced over 1,500,000 barrels.

The total production from shallow sands to the beginning of 1926 was 49,258,000; and from the Wilcox sand, 28,305,000, at which time daily production from the latter averaged 32,540 barrels from 130 wells.

DISCUSSION

LUTHER H. WHITE: Regarding that part of the Tonkawa Pool where Mr. Clark finds the white lime to be absent above the Wilcox sand, I should like to ask him if he has noted the presence of asphaltic sand which might indicate the escape of petroleum previous to the deposition of the Pennsylvanian? I should like to state in that connection that I have noted the presence of asphaltic sand under peculiar conditions in the Stroud Pool of Lincoln County, Oklahoma.

OBSERVATIONS RELATING TO THE ORIGIN AND ACCUMULATION OF OIL IN CALIFORNIA

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San Francisco, California

INTRODUCTION

The problems connected with the origin and accumulation of California petroleum are not as yet satisfactorily solved and deserve more attention by geologists. It is the writer's belief that too much has been taken for granted in the past respecting the ultimate source of California oil. The purpose of this paper is to record data, observations, and field evidence, which may have a bearing on these problems and to open a discussion of the subject, in order that new data may be brought forth relative to these fundamental questions.

Practically all of the oil produced in California is derived from Tertiary rocks. To January 1, 1926, there had been produced 2,327,438,000 barrels of oil in this state. By far the greater part of this oil has been found associated with anticlinal structures or structures which in their effect on oil accumulation simulate anticlines. What is the origin of this oil and what are the principal factors which controlled its accumulation and concentration in deposits of commercial value?

Much has been written on the general subject of the origin and accumulation of oil. It has been generally conceded by geologists who are familiar with the California oil fields that the oil was derived from the relatively thick sections of predominantly siliceous shale which, in most fields, immediately underlies the more sandy reservoir rocks from which the oil is produced. In many localities these shales are rich in the minute fossil remains of diatoms. In some cases they are completely composed of the microscopic siliceous skeletons of these organisms. These shale formations, hundreds of feet in thickness and in part highly diatomaceous, are usually regarded as the source of the oil. California oil-field literature is replete

with references to this theory. In a great many cases this is simply taken for granted. However, there still remains much research to be done before this problem is definitely solved.

Similarly, too much has very frequently been taken for granted regarding the factors governing the migration of oil from its source rocks, and its accumulation in commercial deposits. No attempt will be made in this short paper to discuss the various theories of oil migration or to analyze the complex data relative to the effects on oil accumulation of pressure, temperature, faulting, lines of folding, vertical and lateral movements of gas and oil, drainage areas, water and water movements, flushing, the origin of gas and oil pressures, etc. The writer simply wishes to emphasize that these are parts of a fundamental problem to which more thought should be given and on which more systematic work is needed for the sake of science as well as for the more practical purpose of aiding in the location of new oil pools.

TABULATION OF CALIFORNIA OIL FIELDS

The following tabulation (Fig. 1) of the principal oil fields of California was compiled to show some of the characteristic geologic features relating to the occurrence of oil. The classification of age and thickness of the formations as there given is not final, and at best may serve only as a basis for discussion. It is the writer's opinion, derived from the data at hand, which was compiled from personal field observation and all other available sources.

An analysis of this table shows that of the forty-seven fields listed, thirty-eight, or 80 per cent, of them are located on anticlines, six are on monoclines, or terraces, and three associated with faults. It is also worthy of note that in parts of three fields some oil has been produced from the upper portions of plunging synclines.

Referring again to the tabulation, under the caption "Age of Reservoir Formation," it will be noted that twenty-eight, or 60 per cent, of the fields listed produce oil from formations of Pliocene age. In at least five of these fields, however, there is a lower oil horizon of probable Miocene age. In nine other fields the production is derived only from the Miocene. Seven fields derive their oil from the Oligocene, and one small area in the Coalinga field, worthy of

TABULATION OF THE PRINCIPAL CALIFORNIA OIL FIELDS

THEIR STRUCTURE AND THE AGE CHARACTER AND THICKNESS OF THE SOURCE AND RESERVOIR ROCKS

SAN JOAQUIN VALLEY FIELDS	TYPE OF STRUCTURE: ANTICLINE	TERRACE OR MONOCLINE	FAULT	SYNCLINE	AGE OF RESERVOIR FORMATION: PLIOCENE	MIOCENE	OLIGOCENE	EOCENE	CRETACEOUS	CHARACTER OF RESERVOIR ROCKS: SANDSTONE	SANDY SHALE	FRACTURED ZONE	APPROXIMATE THICKNESS	AGE OF SOURCE ROCKS: PLIOCENE	MIOCENE	OLIGOCENE	EOCENE	CRETACEOUS	SOURCE ROCKS	THICKNESS
COALINGA																				
EAST SIDE	X			✓		X			X	X			150 ±			X		X	SHALE	1000
WEST SIDE		X				X				X			100 ±			X			-	150
LOST HILLS	X				X	✓				X			900 ±		X				-	3900
DELUDGE	X				X					X			200		X				-	3800
McKITTRICK		✓	X		X					X			50-200		X				-	3000 +
MIDWAY - SUNSET																				
BUENA VISTA HILLS	X				X					X			400		X				-	5000 +
ELK HILLS	X				X					X			300-800		X				-	5000 +
FELLOWS		X		✓	X					X			125-300		X				-	4000 +
33 HILL	X				X	X				X			150-600		X				-	5000 +
MARICOPA		X		✓	X	X				X			100-400		X				-	5000
WHEELER RIDGE	X				X	X				X			200-300		X				-	5000
KERN RIVER		X			X					X			100-300		X				-	100
SANTA BARBARA FIELDS																				
SANTA MARIA	X				X	X				X			30-400	X					-	6500
CASMALIA	X		X			X						X	80-120	X					-	5000
CAT CANYON	X				X	X				X			25-700	X					-	6500
LOMPOC		X			X								200	X	X				-	6000
SUMMERLAND	X									X			10-100	?	X				-	5000
VENTURA CO. FIELDS																				
SOUTH MOUNTAIN	X						X			X			50-300				X		-	2000 +
SESPE	X				✓		X			X			300-600				X		-	2300 +
MODELO	X					X	✓			X			200 ±		X				-	5000 ±
HOPPER CANYON	X					X				X			50-100		X				-	2000 ±
SUL - BALDWIN MOUNTAIN	X				X	✓				X			75-100		X				-	2000 ±
CONEJO			X			X				X		X	200 ±				X		-	?
MONTEBELLO OR SHELLS	X						X			X			200 ±				X		-	3000 +
TORREY CANYON	X						X			X			50-180 +				X		-	3000 +
BAKERSDALE	X						X			X			400-500 ±				X		-	3000 +
SIMI VALLEY	X						X			X			200 ±				X		-	3000 +
EUREKA CANYON	X						X			X	X		100 ±				X		-	3000 +
VENTURA RIVER	X				X					X			100-500			X			-	3000 +
NEWHALL DISTRICT																				
FIGG & WILEY CANYON	X					X				X			200-600				X		-	1000 ±
ELSMERE CANYON		X			X					X			1200 ±		X				-	1500 ±
SOUTHERN CALIF. FIELDS																				
SALT LAKE	X		✓			X				X			200-300		X				-	2100 - 3000
LOS ANGELES CITY	X					X				X			200-300		X				-	2000 - 3000 +
MEXICO HILLS	X				X					X			1100 ±		X				-	-
EAST WHITTIER	X		✓		X					X			200 ±		X				-	-
BREA - OLINDA	X		✓		X					X			100-700		X				-	-
WEST COYOTE HILLS	X				X					X			600 ±		X				-	-
FULLERTON OR EAST COYOTE	X				X					X			600 ±		X				-	-
SANTA FE SPRINGS	X				X					X			1300 ±		X				-	-
RICHFIELD	X				X					X			1100 ±		X				-	-
DOMINGUEZ & ATHENS	X									X			300-600 ±		X				-	-
SIGNAL HILL - LONG BEACH	X				X					X			1200 ±		X				-	-
HUNTINGTON BEACH	X				X					X			1500 ±	X	X				-	-
TORRANCE - REDONDO	X				X					X			100-350 ±		X				-	? - ?
PUENTE	X				X					X			700 ±		X				-	2000 - 3000 ±
HOLLYWOOD	X				X					X				X ?	X				-	-
TOTAL FIELDS 47	35	6	3		25	14	7		1					7	25	2	9	1		

X - PLACE PRODUCTION ✓ - MORE DOUBTFUL

FIG. 1

note only that it might be classed as an exception to the rule, produces some oil from the Cretaceous.

It has been stated by R. W. Pack that wherever large quantities of oil are found in California a large thickness of shale is associated with the oil-producing horizons. Quite generally this shale has been considered to be of Miocene age. As herein tabulated, formations of Miocene age of such a character that they might be classed as the ultimate source of oil, are found in thirty-five fields. It is, however, probable that in six of these fields there may also be source beds of Pliocene age. In the two Coalinga fields, the source rock is classed as Oligocene, and in nine fields the Eocene is considered to be the source.

RESERVOIR ROCKS

The reservoir rocks or formations are comparatively soft sandy beds interstratified with minor amounts of clays or shales. Many of the wells in some districts log sandy shale showing oil. In many cases, as pointed out by R. W. Pack,[1] these are fine-grained sands. The reservoir formations are thick as compared to other large producing fields in the United States. In many fields the formations containing the oil are divided into zones, which are separated by barren formations or water sands or both. Within the oil zones the oil sands may be lenticular or grade from coarse sands to sandstones or to sandy shales or clays. In many cases, however, the great irregularity noted in a close comparison of logs is, in part at least, due to the difficulty of obtaining a correct and uniform interpretation of the material penetrated by the drill.

The table (Fig. 1) gives the approximate thicknesses of the oil-bearing formations of the various fields. It is noteworthy that some of these reservoir formations are from 100 to more than 1,500 feet thick. In some fields the known oil-bearing strata, eliminating barren clays, shales, and water sands, aggregate over 700 feet in thickness. Above the oil-bearing formation a true, hard, impervious cap rock is seldom found. As a rule, the overlying formations are more or less unconsolidated sediments commonly containing some clay beds. Occasionally a few fossils are found associated with the

[1] *U.S. Geological Survey Professional Paper 116.*

oil-bearing formation but neither the oil sands nor the interstratified beds are to date known to contain organic remains in such quantities that they could, in general, be regarded as the source of the oil. In the Los Angeles Basin, shales containing Foraminifera and some diatoms are closely associated with the reservoir rocks. In the Huntington Beach field, in Inglewood, and possibly in other of the Los Angeles Basin fields, where our data is extremely meager on this subject, shales rich in foraminiferal remains might be considered as contributing to the source of the oil. This is worthy of consideration for the reason that the large bodies of underlying Miocene shales are separated by hundreds of feet of barren clays, sands, etc., from the producing horizons. However, it is probable that faulting has been an important factor in the migration of oil from the underlying source rocks. The Pliocene foraminiferal shale strata are comparatively thin and seem inadequate to have produced 50,000 to over 200,000 barrels of oil per acre. Such yields are obtained from some of the better, restricted areas.

Careful, systematic microscopic work has not been done to a sufficient extent on the cores or cuttings from the reservoir rocks penetrated by the wells, and, while such scientific work might reveal some interesting results, the possibility of finding that the oil was formed *in situ* is questionable. This work and a study of whether or not foraminifers are of a character which could produce oil, and if so (which is probably the case) whether they are in sufficient quantity to serve as a source, are questions certainly worthy of careful consideration. Furthermore, there is the possibility that the original organic material may have been transformed to some type of petroleum contemporaneous with the deposition of the formations in which it is now found and deposited with them, or, if formed later, that the original material is entirely lost; i.e., no fossil evidence remains. However, the greater part of the reservoir rocks of California are relatively near-shore deposits and were laid down under conditions unfavorable for the accumulation of large quantities of organic material, sufficient in amount to account for the large quantities of oil. Such sediments not associated with thick shale series are barren of oil. As the table shows, thick shale formations underlie all the oil producing horizons.

Before taking up the question of the geologic evidence that the oil may be derived from parts of these shale formations, the relationship of these shales to the overlying reservoir formations should be mentioned. In the San Joaquin Valley fields, the reservoir formations, as previously stated, are largely sandy, near-shore sediments and are underlain unconformably by organic shales.

There are two exceptions to the foregoing general statement: (1) A small amount of oil is produced from the upper member of the Cretaceous in a small division of the East Side Coalinga field from sandy beds apparently conformable with black shale strata. (2) A considerable amount of oil from limited areas has been found in the shale series below the unconformity with the overlying sandy reservoir rocks. This production is from a sandy phase in the shale series and is best characterized in the Hovey Hills–Sunset areas. The unconformity at the top of the shale series is regional and is well defined by differences in dip and strike, by a change in fauna, and by lithology. The reservoir rocks are observed resting across the more highly tilted beds of the underlying shales. Though definite evidences of unconformity are not clearly defined in all localities, there was a period of regional uplift subsequent to the deposition of the shale series and prior to a period of subsidence during which time the reservoir rocks were laid down.

In the Santa Maria fields, some oil is produced from the Vaqueros (lower Miocene) and from fractured zones in the Monterey (middle Miocene). The bulk of the oil, however, is produced from the lower Pliocene. Although locally the lower part of the lower Pliocene contains some shales, in general, an unconformity separates the Pliocene reservoir rocks from the Monterey shale series.

In the oil fields of Ventura County the upper oil reservoir horizons also occur in the Pliocene, or the Fernando group. This group is in general separated from the underlying shales by an unconformity. There are general unconformable relations found between the reservoir rocks of the lower light oil and an underlying shale.

In the southern California fields a large part of the production comes from reservoir rocks which lie unconformably above a series containing thick shale measures. It is also probable that some oil is

found in sandy beds which in some localities form the top or upper members of the Modelo formation or shale group.

While it may not be universally true, it is observable in many of the California fields that an unconformity exists between the oil reservoir formation and the underlying shales. If the shales were the source of the oil, pertinent questions are: When did the transformation from the original organic material to the oil take place? What factors caused its migration?

POSSIBLE SOURCE ROCKS

The Tertiary shales, so generally classed as the source of the California oil, are of four geologic ages—Pliocene, Miocene, Oligocene, and Eocene. Relative to the oil produced, the Miocene shale series is the most important and on this account receives fuller treatment than the others. The Midway-Sunset, McKittrick, Lost Hills, Belridge districts, most of the sourthern California fields, part of the Santa Maria fields,[1] and a part of the Ventura County fields have shale formations known variously as the Monterey shales, Maricopa shales, the Puente, and the Modelo. These possible source shales range in thickness from 1,000 to over 5,000 feet, and are relatively soft and siliceous. Generally they weather to a yellowish color, though locally the shales may have a white, chocolate, or brownish cast. Except for microscopic and nearly microscopic forms, these shales are almost devoid of fossils. Thin, hard, yellowish strata of limestone, from an inch to 2 or 3 feet in thickness, in part at least foraminiferal, are very commonly associated with the shales. While generally the shales would be classed as moderately soft, they have in some localities become silicified to a chert. In other places they are so soft and fine that they may be broken or pulverized in the hands. This great group of shales has for many years been popularly known as the Monterey shales. They have been called diatomaceous shales and have been considered the source of the oil. In support of this hypothesis, Kramer and Spikler point out a possible derivation of petroleum from diatoms. According to these investigators, these organisms contain drops of oily matter and

[1] A part of this shale series has recently been determined as lower Pliocene in a part of the Santa Maria–Lompoc area.

from diatomaceous peat a waxy substance resembling ozokerite can be extracted. As Professor E. T. Dumble points out:

> It is well to remember the enormous accumulations of oozes, namely, the radiolarian and globigerina oozes on the bottom of the sea. The organic matter thus indicated is certainly abundant enough, if it can decay under proper conditions to form more hydrocarbons than the known deposits of petroleum now contain.[1]

It is a well known and easily observable fact that (1) associated with the oil fields in California are many thousand feet of sediments; (2) in the oil fields so far known the oil reservoir formations are all closely assocated with that part of the section occupied by shales; (3) thousands of feet of strata not closely adjacent to the shales are barren of oil; (4) on the other hand, large areas of shale of great thickness are known which have produced no oil.

Shale samples from various localities have been microscopically examined and some shale strata found to be very rich in the remains of minute organisms with Radiolaria predominating. Practically all of the geologists of the U. S. Geological Survey in their studies of the California oil fields class the shales in general as organic, but so far as the writer is aware, no systematic study from samples representative of the great mass of the shale in any one of the oil districts has been completed and the results published.

Some of the shale composed of diatomaceous material is very light in weight, a gray-white to light yellow in color, and though coming from an oil-field area, contains no trace of oil, either by solution or distillation test. Numerous tests by the writer on the heavier yellow to brown shales showed no trace. If oil originated in these shales the process by which the whole of the hydrocarbon content was removed is very complete.

Oil in a free state is found in various localities in some of the shale strata. This is in part readily dissolved out by solvents. Some hydrocarbons, possibly so called "kerogen," are also found in some shale beds, which are not affected by solvents but upon distillation are easily recognized. Several hundred field tests on shales of all

[1] For a further discussion and more complete references on this phase of the subject the reader is referred to: Clarke, *Data of Geo-chemistry;* Dalton, *Economic Geol.*, Vol. 4, No. 7, October–November, 1919; Vol. 3, No. 4, 1908.

types were made by the writer and fifty-odd samples were tested in the laboratory. These samples were taken from all of the principal oil districts in California.

The light-colored shales, both the hard cherty types and the soft friable types failed to show the presence of more than a trace of oil by either solvent or distillation. The analyses were not of a kind to determine the presence of very minute quantities of hydrocarbons, hence positive conclusions cannot be drawn and further investigations, coupled with microscopic work, would be of interest. These light-colored shales in many instances constitute the greater part of the shale observed in the field. There are darker colored shales which when broken are of a chocolate to brown color. They give off an oil by distillation, in quantities varying from a trace to nearly 30 gallons per ton. Under the microscope some of these darker shales can be seen to contain carbonaceous or hydrocarbonaceous material, but not abundant diatoms or foraminifers. Comparatively few samples were examined and further investigations along these lines would be valuable. It is possible that some types of shales are more capable of holding their oil or hydrocarbon content than others, but data collected suggest that only parts of the shale series are organic in respect to being the source of the oil and the question can be raised: "Were the diatoms in the principal or only source of the oil, or should we look further for some other type of organic material from which the bulk of the California oil may have originated?"

Many geologists working in the oil fields have without doubt gathered interesting and valuable field data relative to some of these problems and they should record and publish these observations, small though they may seem, in order that eventually the accumulated material may make possible a better understanding of the facts relating to the origin and accumulation of oil.

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A CRITICAL EXAMINATION OF THE EQUAL POUND LOSS METHOD AND OF ESTIMATING GAS RESERVES[1]

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The "equal-pound-loss law" is a rule used in natural gas appraisals, based on Boyle's Law for the behavior of perfect gases, which states that for each pound of closed pressure loss, a constant quantity of gas will be produced. In the form of an equation:

$$PV=k\,,$$

P representing pressure, V representing volume, and k, a constant where the temperature is constant.

Closed pressure is sometimes called "rock pressure" and is the maximum pressure above atmospheric pressure which a gas well will exert when shut in and in a state of equilibrium.

The experience of the authors, who have found all gas pools which they have calculated to deviate materially from this approved law, leads to the following critical considerations of the theory on which the law rests.

1. The underground losses which reduce the pressure but are not shown in the yield are not constant throughout the life of the well. Those that arise from such causes as the packer and the casing are very great at the beginning, since all leaks give a greater proportional loss when the pressure is high. Deterioration, on the other hand, causes a larger proportionate loss in the later life by the increase in the number and size of the leaks. It could not be assumed that these losses compensate because of their widely different order of magnitude.

2. The encroachment of water does not reduce the reservoir at such a rate as to keep the pressure constant on the one hand, nor

[1] Read before the Association at the Annual Meeting, Wichita, Kansas, April, 1925.

on the other to reduce the volume at a uniform rate. It is obviously dependent for its rate on the pressure differential of the surrounding rocks and the reservoir, and since the differential increases, the rate of encroachment increases. This fact alone, wherever there is water encroachment, makes the equal-pound-loss law fallacious.

3. Technological irregularities are not, in most cases, equally distributed throughout the life of the well. The average well has a period in its early life when the pressure of the well is above the pressure of the line, and it is "pulled on" relatively uniformly at a gradually decreasing rate; however, as it approaches line pressure its yield becomes subject to frequent technological irregularities, as the line pressure changes.

4. Where there is no water or oil, it may be concluded that the peripheral zone of the reservoir is gas filled. There appear two cases. The first in which the reservoir is typically and essentially a nucleus of high porosity, surrounded by successive zones of sand having diminishingly less porosity, till finally the rock has a permeability too low to permit motion at a rate adequate to affect the calculations.

Under these circumstances gas is produced at first from a reservoir of a limited radius, since the pressure differential is too low to make significant flow from the other zones. But as pressure at the well decreases the pressure differential increases and so gas from additional zones begins to move toward the hole, so that eventually a reservoir of larger volume than at first is producing, through rocks, however, of lower permeability.

In the second case of the peripheral zone of the gas-filled reservoir, a reservoir A exists, which may be connected with another reservoir B, which for purposes of illustration may be likened to two reservoirs connected by a pipe. Under these circumstances, significant flow from B to A starts in only after the pressure of A has been materially reduced.

5. The yield per pound loss of a pool is not independent of the number of wells. During the first hundred pound loss, the entire production may be drawn from a few wells, and these "pulled on" for a large part of their capacity. Such wells produce less gas per pound loss than takes place where the complete set of wells are in and produce at the normal rate.

6. The seasonal cycles become more marked with age. In such older wells, there is a decrease in the pressure gradient during the relatively idle season. Such wells produce more per pound loss than where the seasonal load varies less.

7. In the consideration of the gas itself, it is found that methane does not follow Boyle's Law over even a moderate range of pressures. Boyle's Law states that the volume of a gas varies inversely as the pressure, temperature considered constant. Early physicists noted its inadequacy. Van der Waal made two corrections: (*a*) Allowance should be made for the volume that the molecules themselves occupy, a constant b, resulting in the equation:

$$P(V-b)=k\,.$$

(*b*) As the gas becomes compressed and the molecules become closer together, their intermolecular attraction must be taken into consideration in reducing the pressure that the gas exerts. A constant $\frac{a}{V^2}$ is thus introduced, leaving the equation in the form:

$$\left(P-\frac{a}{V^2}\right)(V-b)=k.$$

In practice, deviations are found, but they do not conform to this formula and it is merely pointed out as a partial cause of the discrepancies.

The cause of the greatest limitations of any general rule for the relationships discussed is the chemical composition of the gas. These deviations for several of the constituents of natural gas have been given by Burrell and Robertson.[1]

The wide range in composition of natural gas, even within a small area, shows that in the appraisal of a reservoir, a single gas alone is not dealt with, but a mixture of several gases, and as a result of this, of several compressibilities.

The authors know of no commercial pool where the yield per

[1] G. A. Burrell and I. W. Robertson, "The Compressibility of Natural Gas and Its Constituents, with the Analysis of Natural Gas from 31 Cities in the United States," *U.S. Bur. Mines Tech. Paper 158*, 1917.

pound loss remained constant throughout its life and they believe on theoretical grounds that this will be very rare.

The theoretical chances of a pool complying to the law seem to be slight. The use of this method on the ground that it ought to apply is unwarranted. It should be applied only in those rare cases where trial shows that the yield per pound loss in successive time units is substantially constant, or where the deviation is slight enough to ignore the error.

There is a further statistical difficulty in the use of this method which is illustrated in the case of McKeesport, Pennsylvania. The equal pound loss is tantamount to extrapolating the curve of gas produced per pound loss as a horizontal line, not from the end of the curve, but at a point which may be above or below that, as determined by the mean relationship, so that the well is predicted to increase or decrease its production suddenly the first year of the extrapolated curve. If one must use this method, it should at least be based on the yield per pound loss of its later life and not on the average of its whole life.

The purpose of this paper, however, is to suggest that the best method of estimating future production of gas wells from pressure data (and there are times when estimating the future production from yield itself, as in oil, is the best method) is to make a curve of the yield per pound loss by successive time units and to extrapolate this line directly, or if curved and not subject to being straightened on any of the well-known rulings to derive an empirical formula by which the future years can be calculated. From this curve and a postulated pressure decline curve, a yield curve is readily calculated.

GEOLOGICAL NOTES

GAS AND OIL NEAR EDNA, JACKSON COUNTY, TEXAS

In the vicinity of Edna, Jackson County, Texas, large volumes of gas resulting in "blowouts" of considerable intensity have been found in two wells and a third has been completed as a commercial producer. The gas from this well is now going to Houston through the recently completed line of the Houston Gulf Gas Company. An interesting feature of this gas is its turpentine-like odor and the occurrence with the gas from two wells of a small amount of a light oil with the same odor as the gas. This oil appears to be the same as that found in small amounts in a number of Gulf Coast gas fields, and in one case mixed with shallow petroleum in an oil field. A very similar oil from Anse La Butte, Louisiana, was determined by Coates and Best to be a dicyclic hydrocarbon having the general formula: C_nH_{2n-2}. This series of oils is very different from petroleum and from turpentine; nor is it a terpine, as it has, in some cases, been called. Information on these turpentine-like oils is meager and few samples large enough for chemical analysis have been secured. A similar occurrence from the Terrebonne gas field, Louisiana, has been reported in the bulletin of this association[1] by Alexander Deussen. Information as to other occurrences of similar oils and drip condensates with a turpentine odor will be appreciated.

W. ARMSTRONG PRICE

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2, p. 21.

REVIEWS AND NEW PUBLICATIONS

Interpretation of Topographic and Geologic Maps. By C. L. DAKE and J. S. BROWN. McGraw-Hill Book Co., 1925. Pp. 355.

Topography, like the rest of nature, "speaks a various language." Even those whose particular delight in the work has led them to spend years trying to interpret topography in terms of structure, stratigraphy, and geological history are not uncommonly bewildered or misled into erroneous statements, and most geologists may justifiably refuse to place confidence in its apparent significance until more definite observations on the rocks themselves have been made. Yet topography, or better physiography, is the tool readiest to the hand of the geologist who enters a new region, and willy-nilly he must depend on it if he is to cover country rapidly. Particularly does this apply to the petroleum geologist, and any new publication that promises to make his interpretation of topography more accurate will deserve his attention and approval.

Dake and Brown's *Interpretation of Topographic and Geologic Maps* seems, to the reviewer, to have achieved with reasonable success their apparent purpose of combining a handbook for the field man with a manual for the laboratory. Both are badly needed. A combination of the two is a logical thing, yet to attempt such a work required no small courage. Obviously it would be impossible to include the many plates that make Atwood and Salisbury's "Interpretation of Topographic Maps" (*U. S. Geol. Survey Professional Paper No. 46*) such a boon to the student of physiography. The space limits of the handbook would absolutely bar them and the cost of a multitude of expensive illustrations would make the work undesirably costly for a laboratory manual. The only alternative was to refer to the necessary illustrative material, selecting the references carefully so that they would be reasonably available, and to attempt to so word the discussions that they would project a picture upon the mind of the reader. For the most part this has been very effectively done, and it seems to the reviewer that the absence of maps in the book itself is really an advantage to the man who has access to fairly complete files of the publications of the U. S. Geological Survey which constitute the references, for he can read the text with a smooth, separate map in front of him and does not have to laboriously and carefully unfold a map that has been inserted into the text, nor to continuously flip the leaves to refer back or forward to some particular sheet.

No part of this book seems superfluous. On the contrary, the discussions are all too brief and it is hoped that in the next edition certain features will be given more space. For example, it seems that the discussion of the work of ground water might be expanded to include the depressions due to the solution of salt that in some instances mark the locations of salt domes. Such depressions commonly contain marshes or ponds in which the water may or may not be saline. In many instances these ponds or swamps are rimmed by low hills that

are thought to express topographically the most recent upward movement of the salt plug. No discussion of these features would be complete without calling attention to the somewhat similar hollows that abound in parts of the wind-swept coast of the Gulf of Mexico and that are due to deflation. These wind-formed depressions may be distinguished from the hollows resulting from solution, since the prevailing winds are commonly from some particular direction, and low hills on the lee side of the hollows where the winds deposit much of the sand and silt which they scooped up present a contrast to the hill-less windward side.

Depressions that mark the crests of anticlines are given passing mention in the text, but the oil geologist would be glad to see much more discussion of such features. For example, it seems logical to believe that solution by ground water will be greatest where very soluble beds lie near the surface, and it would follow that isolated sinks in a region underlain by salt or gypsum may indicate that the soluble material was closer to the surface beneath the sink than elsewhere with the reasonable inference that the proximity to the surface was due to folding or faulting, while a line of depressions or sinks may indicate the concealed outcrop of a very soluble bed.

The discussion of the relation of land forms to structure, to which 73 pages are devoted, will probably be the most popular part of the book with the petroleum geologists. "Drainage patterns and structure" immediately brings to mind "Creekology" and its undoubtable success in some regions where broad curves or abrupt changes in direction reflect the adjustment of the stream courses to the geologic structure. At the same time most experienced geologists can bring to mind numbers of dry holes located in the bends of rivers or creeks where the apparently abnormal conditions were due not to structure, but to simple meandering, to stream piracy, to glaciation, or some other non-structural reason. A point that seems worth raising in connection with the response of streams to structure is that *local* absence of meanders may signify recent uplift. If there is uplift across the course of a meandering stream, the energy of the stream may be so consumed in cutting through the rising obstruction that the part of its course across the uplift will be relatively straight, while above and below the uplift the stream will spend its energy in lateral planation with consequent development of broad meanders, rather than in down-cutting. This criterion is, of course, useful only in regions that have been recently deformed and where the recent deformation may indicate the position of earlier folding that has influenced the accumulation of oil.

This consideration of recent deformation brings up a statement to which many geologists, and particularly those working in California, will perhaps take exception. The authors state, "Since structure is reflected in topography only when erosion has etched out the softer rock leaving the harder in relief, it is obvious that the structural record will be most striking in those stages of the cycle in which relief is considerable" (p. 135). This ignores the topographic expression of recent folding and faulting. In parts of California the structure is manifested by very youthful topography, and this also holds true in some salt-dome regions. It seems particularly odd that this statement should face a page

that carries an illustration of salt-dome topography which certainly is not a structural expression developed during middle youth to middle maturity.

An admirable point in this book is the evident effort that has been made to avoid dogmatism, and to point out the many exceptions to the generalizations that are made. The double purpose of the book—a field handbook for working geologists and a laboratory manual for students—makes this difficult because the field man wants to know of all the possible exceptions, while the student must not be confused by elaborate discussions of a multitude of exceptions that may not be easily understood. All things considered, the difficulty has been handled remarkably well.

The reviewer would take exception to the statement that "Terracing, either by streams or by wave work, implies unconformity between the deposits of the terrace level and those of adjacent higher lands" and that "the recognition of a terrace generally implies the recognition of an unconformity" (p. 198) since this commonly is not true of terraces of erosion. Many terraces carry no veneer of recent material whatsoever. The "terraced plains" of the Mid-Continent, which have resulted from stream activity although not from lateral planation by the stream itself would call for a multitude of non-existent unconformities if the rule were unintelligently applied.

Part II of the book deals with the interpretation of geologic maps. The reviewer believes this is less likely to improve the work of the oil geologist than is the first part since it deals with a phase of geology in which he is more expert and less in need of aid. Practically all practicing oil geologists have prepared geologic maps and "he who can write, can read." The data, presented in Part II, are, for the most part, elementary and are more or less apparent to one who has spent time considering a geologic map as a three-dimensional picture, but nevertheless, study of this section must benefit anyone concerned in increasing his speed and accuracy in interpreting geologic maps.

Some parts of Section II are of benefit solely for classroom exercise. These the experienced reader will recognize without difficulty. He may take exception to some of the generalizations, as, for example, the statement that variations in the thickness of a formation which may occur in a short distance are unlikely to make "an appreciable difference in the width of outcrop." The authors obviously were considering the thickness of the formation as originally deposited and had no intention of covering the differences due to squeezing of shales or to unconformable relations, but even so the statement is hardly defensible and it should, of course, be protectively qualified.

A statement in the introduction of Part II should meet with particular approval. A geologic map "represents only the closest approximation to the facts that it is possible to get with a *reasonable* expenditure of time and money." We all know this is true, but it is sometimes forgotten in the enthusiasm of "improving" a predecessor's work.

K. C. HEALD

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The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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TULSA MEETING AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS, PETROLEUM DIVISION

To the President, American Association of Petroleum Geologists:

The mid-year meeting of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers will take place at Tulsa, Oklahoma, October 11–14, and a tentative outline of the program is inclosed herewith. This meeting will be held in co-operation with the Mid-Continent Section of the A.I.M.& M.E. and the Mid-Continent Oil & Gas Association.

It would be much appreciated if special representatives of your organization can be present and also be advised to feel free to attend and participate in the discussions at our several sessions.

(*Signed*) F. JULIUS FOHS
Chairman, Petroleum Division,
A.I.M.& M.E.

MEETING OF PETROLEUM DIVISION, AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS, IN CO-OPERATION WITH MID-CONTINENT OIL & GAS ASSOCIATION AND MID-CONTINENT SECTION, A.I.M.& M.E., TULSA, OCTOBER 11–14, 1926

INCREASING PRODUCTION FROM OIL FIELDS, WITH SPECIAL ATTENTION TO MID-CONTINENT

I. Increasing recovery in new pools
   1. Solubility of gases in crude oils, and resultant effects upon viscosity and surface tension
   2. Modern methods of equipping and handling flowing wells in mid-continent fields

3. Gas-lift flowing of wells in the mid-continent district
4. Methods of handling pumping wells to conserve gas
5. (*a*) Advantages of unit operation in oil fields
   (*b*) Economic effect of increased recovery methods

II. Salvaging oil in developed pools
1. Increasing recovery in mid-continent fields and its economic effects
2. Application of Marietta process to Delaware pool
3. Comparison of pressure and vacuum methods of production
4. Economic effects

III. Improved drilling and production methods
1. North-central and east-central Texas
   (*a*) Methods used in the Powell field in determining water shut-off levels and methods of effecting shut-off
2. Gulf coast fields
3. Oklahoma and Kansas
4. Panhandle district
   (*a*) Drilling practice
   (*b*) Production problems
5. Economic effects

IV. Mid-Continent Oil & Gas Association banquet (addresses by some of the heads of the industry)

V. A.I.M.& M.E. subscription luncheon to plan establishment of local clubs affiliated with division and discuss methods of electing division officers

VI. Trips to Oklahoma oil fields where special methods are in use

Memorial

WILLIAM KENNEDY

The early morning of February 23, 1926, marked the passing to the great beyond of one of the most beloved and picturesque characters in the geological profession, when William Kennedy died at his home in Fort Worth, Texas.

To write a complete and accurate story of the life of this great and good man would be particularly impossible for the reason that he was of such an unassuming nature and so opposed to publicity that his closest friends knew little of his personal affairs and domestic life. Many were the personal questions propounded to him by those interested in his welfare, but few were the answers that had any direct bearing on himself. In direct contrast, however, it will not be amiss to say that on any other subjects, and especially those relating to some phase of the petroleum industry, he was most liberal, pouring out his vast store of knowledge to the thirsty. Many were they who drank freely thereof, to their extreme satisfaction and benefit.

Mr. Kennedy was born in Scotland and there spent his boyhood days. In his early youth, he became an ardent student of mathematics and attained proficiency in this and kindred subjects. His higher education was had at Edinburgh University and there he maintained his high standard of scholarship. Owing to his mathematical ability, he became interested in navigation and subsequently went to sea as a navigating officer, sailing on the old-time four-masters which are illustrated in history books of today. While thus engaged, it may be said that the foundations of his future were laid, since this line of work naturally brought on the study of oceans and coast lines.

After spending some time at sea, he was sent out by the Bank of British North America to New Brunswick, Canada, and in such capacity was stationed in several Canadian cities. It was through this means that he located at Hamilton, Ontario, where he met and married Miss Margaret S. Richardson. To this union two sons were born, William R. and James B. Kennedy. The latter died in his infancy, living less than a year, while William, who became interested in the oil industry, was connected with the Rio Bravo and Gulf companies for some time before his death about three years ago.

It was during his sojourn in Canada that William Kennedy became interested in mining, and it was then that the mysteries of Mother Earth took a hold on his natural ability that was never relinquished. This was the spark that kindled the blaze with which he was destined to enlighten the geological horizon in many ways. His ventures in the mining industry were a series of ups and downs, but he never lost interest in mining even in later years when fascinated with the romance of oil. This was evidenced many years later by his explorations of, and publications on, the iron ores in east Texas.

When his mining ventures in Canada failed to come up to expectations, he went to the Mid-Continent and Gulf Coast country and there began the era in his life that has been of inestimable value to the science of geology and the

WILLIAM KENNEDY

petroleum industry, as well as to his innumerable friends and acquaintances. As a pioneer geologist in Arkansas, Louisiana, Oklahoma, Texas, and Mexico he worked the country in a wagon, long before geology was dreamed of as the tremendous aid it has now proved to be to the oil industry. Those were the good old days when a rope was tied around the rim of a wagon wheel and the revolutions were counted, in order to determine the distance traveled.

It was about this time that he became associated with the Arkansas Geological Survey and his first real work as a geologist began. He also spent some time on geological investigations in Tennessee before joining the staff of the Texas Geological Survey in 1890, at which time Dr. E. T. Dumble was state geologist. With the advent of the *Second Report of Progress* (*Texas*) in 1891, his publications began to appear. These included reports on "Houston County (Texas)"; "A Section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico (Texas)"; "Grimes, Brazos and Robertson Counties (Texas)"; "Iron Ores in East Texas"; "The Eocene Tertiary of Texas, East of the Brazos River"; and with C. W. Hays, the now famous *U.S.G.S. Bulletin No. 212*, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," which is highly prized and still considered authoritative by geologists of today.

After leaving the Texas Survey, Mr. Kennedy went with the Southern Pacific Railway and later with the Rio Bravo Oil Company, during which time he wrote many valuable reports that were, of course, never published. His work with these companies kept him in the coastal country, and while with the Southern Pacific his territory extended as far west as California and south into Mexico. He was rapidly becoming known as an authority on the geology of the Mid-Continent but more especially the Gulf Coast area, being called by many the "Daddy of the Salt Dome Country." During the years he was studying the Gulf Coast region and Mexico, he was more or less closely associated with many men of the "Old School," among whom were Dr. E. T. Dumble and Professor W. F. Cummins. It may be mentioned in this connection that the days of Spindletop were the days of Mr. Kennedy's prime as a geologist. Not only did he "geologize" but he also engaged in a considerable amount of actual drilling and performed other duties that enabled him to know the "oil game" from every angle.

For several years he maintained an office at Houston, Texas, as consulting geologist and engineer, doing considerable railroad engineering as well as geological work. From Houston he moved to Fort Worth, Texas, assuming the position of chief geologist for the Lone Star Gas Company, in which capacity he acted until his death. He was also consulting geologist for the S.M. Swenson interests of New York City and the Freeport Sulphur Company of Freeport, Texas. It was during his connection with the Lone Star Gas Company that he did some very remarkable work in southern Oklahoma. Three long lines of folding, paralleling the Arbuckle Mountains on the south, were outlined by him before any production of consequence had been found in that area and nearly all production found there since has been almost directly located on one or another of these lines, an accomplishment that would swell the breast of most men, but for which Mr. Kennedy took no credit.

The membership lists of many geological and other societies and associations contained, at one time or another, the name of William Kennedy. Chief among these are the following: American Institute of Mining and Metallurgical Engineers, The American Association for the Advancement of Science, American Association of Petroleum Geologists, Geological Society of America, American

Petroleum Institute, Mid-Continent Oil and Gas Association, The Hamilton Association, and the old Texas Academy of Science. He was also a Master Mason and a member of St. Johns Chapter of the Royal Arch, of St. Johns, New Brunswick.

The thousands of friends who knew Mr. Kennedy, "And none knew him but to love him," will miss him most sadly from life's highway, but his splendid example of true manhood will endear his memory and keep it alive in each of his friends and admirers so long as life endures with them. His was a most genuine, honest, and lovable character, genial, true as steel, generous-hearted, kindly in nature, at all times and in all places a perfect gentleman. It could be truly said by all who were so fortunate as to have known him, and especially those who had known him longest, that

> Time but the impression stronger made,
> As streams their channels deeper wear.

Mr. Kennedy's last days were spent in Fort Worth, Texas, whence he traveled daily, by interurban, to the Lone Star office at Dallas, until about three months before his death. This strenuous daily travel, no doubt, shortened his life, but he could not be persuaded to give up the work he had learned to love so dearly. After becoming interested in geology and the petroleum industry, he lived almost entirely for those two things and they seemed to keep him happy at all times. Nothing gave him more pleasure than the unknotting of some tangled problem on one of these subjects or sharing a part of his vast knowledge with those who sought his expert advice. Some form of throat affliction began to trouble him early in 1925, and this, combined with a case of influenza in the closing days of the year, left him ailing never to recover. Although he suffered a great deal during his illness, he breathed his last more or less easily, and in the still, quiet hours of that February morning a great and good man passed from among us,

> Like one who wraps the drapery of his couch
> About him, and lies down to pleasant dreams.

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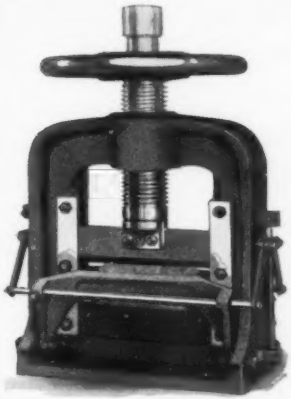

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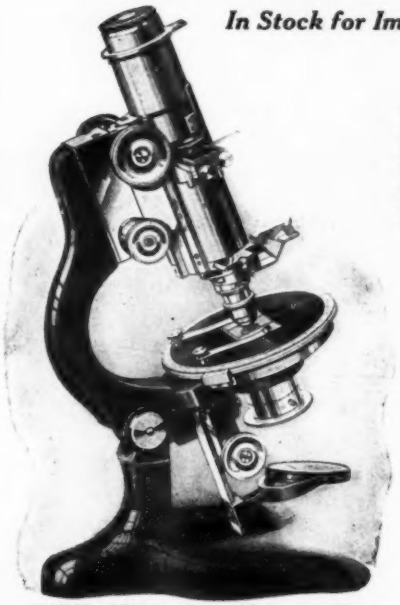

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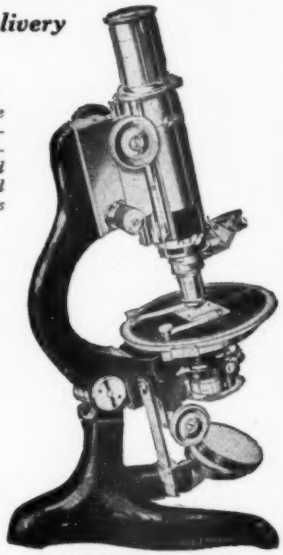

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SALT DOME OIL FIELDS

A SYMPOSIUM ON
THE ORIGIN, STRUCTURE, AND GENERAL GEOLOGY OF SALT DOMES, WITH SPECIAL REFERENCE TO OIL PRODUCTION AND TREATING CHIEFLY THE SALT DOMES OF NORTH AMERICA

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